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LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1870.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Newbold Beeches, Leamington.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Messrs. Addenbrookes Smith and Pidcock, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1870. Alexander, Alfred, Corinium Iron Works, Cirencester.
1847. Allan, Alexander, Bridge Street, Worcester.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Locomotive Superintendent, Moscow and Razan Railway, Moscow, Russia.
1865. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, Messrs. Easton Amos and Sons, Grove Works, Southwark Street, London, S.E.
1856. Anderson, John, Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Messrs. Eastons Amos and Anderson, Erith Iron Works, Erith, London, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.
1867. Appleby, Charles James, Emerson Street, Southwark, London, S.E.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Wolverhampton.
1863. Armstrong, John, Timber Works, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.

1858. Armstrong, Sir William George, C.B., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.
1870. Armstrong, William Irving, Great Western Railway, Locomotive Department, Wolverhampton.
1857. Ashbury, James Lloyd, 9 Sussex Place, Hyde Park Gardens, London, W.
1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.
1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Sheffield.
1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.
1865. Bailey, John, Messrs. Courtney Stephens and Co., Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1866. Baines, William, London Works, Soho, near Birmingham.
1866. Baker, Samuel, 22 Oil Street, Liverpool.
1865. Baldwin, Martin, Bovereux Iron Works, Bilston.
1870. Barber, Thomas, Jun., Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.
1870. Barclay, Arthur, care of Hugh Barclay, Westfield, Surbiton, Kingston-on-Thames.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1866. Barnard, Clement, 11 Billiter Square, London, E.C.
1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.

1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne; and The Hall, Washington, County Durham.

1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street Manchester.

1868. Belliss, George Edward, Agricultural Engine Works, Broad Street, Birmingham.

1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.

1865. Benson, George Henry, Stalybridge.

1867. Berkley, George, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1867. Bernhardt, George, Stand Lane, Radcliffe, near Manchester.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.

1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1863. Birckel, John James, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1866. Birkbeck, John Addison, Sheepbridge Iron Works, Chesterfield.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1865. Bladen, Charles, Provan Mill House, Springburn, near Glasgow.

1870. Blair, John, Chief Locomotive Superintendent, Danish Government Railways, Aarhuus, Denmark.

1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington.

1869. Bloomer, Benjamin Giles, Pelsall Coal and Iron Works, near Walsall.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1869. Borrie, John, Cleveland Iron Works, Middlesbrough.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1862. Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.

1869. Boyd, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.

1854. Bragge, William, Sir John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1854. Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.
1868. Breeden, Joseph, 156 Cheapside, Birmingham.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
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1863. Brown, Henry, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, Sir John, Atlas Steel and Iron Works, Sheffield.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
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1869. Browne, Walter Raleigh, Messrs. John Knight and Co., Cookley Iron Works, near Kidderminster.
1867. Bruce, William Duff, Executive Engineer, Presidency Division, Calcutta, India.
1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.
1865. Bryant, Frederick William, Blackfriars Bridge Works, Chatham Place, London, E.C.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1870. Burgh, Nicholas Proctor, 78 Waterloo Bridge, London, S.
1858. Burn, Henry, Atlas Iron Works, Litchurch, Derby.
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1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, near Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1867. Campbell, Daniel, 10 John Street, Adelphi, London, W.C.
1864. Campbell, David, 105 Eglinton Street, Glasgow.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1869. Campbell, James, Hunslet Engine Works, Leeds.

1860. Cannell, Fleetwood James, Sir John Brown and Co.'s Works, Atlas Steel and Iron Works, Sheffield.

1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.

1869. Carpmael, Frederick, 77 Manor Road, Lewisham Road, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C.

1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Colliery, near Sheffield.

1864. Carrington, William Thomas, 10 Park Street, Westminster, S.W.

1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.

1870. Carver, James, Lace-Bobbin and Carriage Works, Butcher Street, Nottingham.

1869. Caspersen, Hans William, Engineer, Danish Government Railway Service; 11 Elswick Lane, Newcastle-on-Tyne.

1869. Chadwick, John, Junction Foundry, Watson Street, Peter Street, Manchester.

1866. Chapman, Henry, 41 Boulevard Malesherbes, Paris: (or care of George Edward Chapman, 41 Parliament Street, Westminster, S.W.)

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.

1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1869. Clapham, Robert Calvert, Walker Alkali Works, Newcastle-on-Tyne.

1866. Claridge, Thomas, Messrs. Claridge and North, Phœnix Foundry, near Bilston.

1859. Clark, George, Monkwearmouth Engine Works, Sunderland.

1867. Clark, George, Jun., Monkwearmouth Engine Works, Sunderland.

1862. Clark, James, Wellington Foundry, Leeds.

1869. Clark, Thomas, Ironfoundry, Low Elswick, Newcastle-on-Tyne.

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1869. Clark, William, Mining Engineer, Tibshelf Collieries, near Alfreton.

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1863. Clayton, Robert, Soho Foundry, Preston.

1869. Clerk, Francis North, Mitre Galvanising Works, Wolverhampton.

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1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
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1854. Cochrane, John, Woodside Iron Works, near Dudley.
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne.
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1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
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1864. Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
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1865. Corlett, Henry Lee, Great Southern and Western Railway, Carriage Department, Dublin.
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1868. Coulson, William, Mining Engineer, Shamrock House, Durham.
1864. Cowans, John, Messrs. Cowans Sheldon and Co., St. Nicholas and Woodbank Iron Works, Carlisle.
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1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1865. Cross, James, St. Helen's Locomotive Works, St. Helen's.
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1863. Crow, George, Messrs. R. Stephenson and Co.'s Works, Newcastle-on-Tyne.
1864. Crowe, Edward, Messrs. Hopkins Gilkes and Co.'s Works, Tees Side Iron Works, Middlesbrough.

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1866. Daniel, William, 11 Blenheim Square, Leeds.
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1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
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1868. Davis, Henry Wheeler, Resident Engineer, Great Eastern Railway, Stratford, London, E.

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1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
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1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1856. Eastwood, James, Railway Iron Works, Derby.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.
1859. Elliot, George, M.P., Houghton-le-Spring, near Fence Houses.
1869. Elliott, Henry Worton, Metal Sheathing Works, Coleshill Street, Birmingham.

1870. Elsdon, Robert, Brockham Green, near Reigate.
1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Poulot, 9 Avenue Trudaine, Paris.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
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1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.
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1867. Fardon, Thomas, Linslade Iron Works, Leighton Buzzard.
1865. Faviell, Samuel Clough, Messrs. Taylor Brothers and Co.'s Works, Clarence Iron Works, Leeds.
1866. Fenby, Joseph Beverley, 3 Park View Terrace, Soho, Birmingham.
1870. Ferguson, Henry Tanner, South Devon, Cornwall, and West Cornwall Railways, Carn Brea Works, Redruth.
1854. Fernie, John, Ventnor, Isle of Wight.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
1868. Firth, Arthur, Leeds Iron Works, Leeds.
1868. Firth, Samuel, 14 Springfield Mount, Leeds.
1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.
1861. Fleetwood, Daniel Joseph, 58 Broad Street, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1867. Fletcher, Lavington Evans, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.
1868. Forster, John, Messrs. Westray and Forster, Abbey Road, Barrow-in-Furness, Lancashire.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Hall, Walsall.
1847. Fothergill, Benjamin, 15 George Street, Mansion House, London, E.C.
1866. Fowler, George, Mining Engineer, 56 Clarendon Street, Nottingham.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1847. Fox, Sir Charles, 6 Delahay Street, Westminster, S.W.
1866. Fox, Charles Douglas, 6 Delahay Street, Westminster, S.W.
1859. Fraser, John, 18 York Place, Leeds.
1866. Fraser, John Simpson, Peabody Villa, Louisiana Road, Peckham, London, S.E.
1870. Freeman, George Frederick, Broughton Copper Works, Broughton Road, Manchester.
1856. Freeman, Joseph, 98 Cannon Street, London, E.C.
1864. Frost, Thomas, Wadsley Bridge Iron and Steel Works, near Sheffield.
1852. Froude, William, Chelston Cross, Torquay.
1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.
1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1870. Garstang, James H., Bank Top Foundry, Blackburn.
1867. Gauntlett, William Henry, Middlesbrough.
1848. Gibbons, Benjamin, The Leasowes, near Birmingham.
1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.
1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.
1869. Gillies, Malcolm, Great Eastern Railway, Locomotive Department, Stratford, London, E.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.
1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.

1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, 2 Deane Street, Cork.

1870. Gray, Matthew, 100 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1870. Greaves, James Henry, 3 Great George Street, Westminster, S.W.

1861. Green, Edward, Jun., Phœnix Works, Wakefield.

1867. Greenwell, George Clementson, Mining Engineer, Poynton, near Stockport.

1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.

1857. Gregory, John, 57 Millbank Street, Westminster, S.W.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1866. Grice, Edwin James, Stour Valley Works, Spon Lane, Westbromwich.

1860. Grice, Frederic Groom, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

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1863. Hackney, William, Landore Steel Works, Swansea.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)
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1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, William, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1853. Headly, James Ind, Eagle Foundry, Mill Road, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.
1868. Heaton, John, Langley Mill Steel and Iron Works, near Nottingham.
1869. Henderson, David Marr, Chief Coast-Lights Engineer for China, Imperial Maritime Customs, Shanghai, China.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.
1865. Hewett, Edward Edwards, Messrs. Vickers Sons and Co.'s Works, River Don Works, Sheffield.
1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
1864. Hide, Thomas C., Chief Engineer, H. M. Dockyard, Calcutta, India: (or care of Messrs. Holland Jacques and Co., 21 Great St. Helen's, London, E.C.)
1870. Higson, John, Mining Engineer, 98 Cross Street, Manchester.
1869. Hind, Henry, Central Works, Queen's Road, Nottingham.
1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.
1866. Hodgson, Charles, 21 Gresham Street, Old Jewry, London, E.C.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Norton, near Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
1863. Holt, Francis, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.
1867. Homer, Charles James, Mining Engineer, Chatterley Ironstone Works, Tunstall, near Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1860. Hopkins, James Innes, The Poplars, Kingston-on-Thames.

1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.

1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1867. Hopper, William, Machine Works, Moscow, Russia.

1868. Horsley, Thomas, Alfreton Iron Works, Alfreton.

1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.

1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1858. Hosking, John, Gateshead Iron Works, Gateshead.

1866. Houghton, John Campbell Arthur, Messrs. Cochrane and Co.'s Works, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Britannia Iron Works, Bedford; and Dulwich House, Sydenham Hill, London, S.E.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.

1861. Howell, Joseph Bennett, Brook Steel Works, Brook Street, Sheffield.

1866. Hoyle, William Jennings, Sir Joseph Whitworth and Co., Chorlton Street, Manchester.

1868. Hudswell, William Shillito, Messrs. Hudswell and Clarke, Railway Foundry, Jack Lane, Leeds.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1870. Hunstone, William Henry, Springfield Iron Works, Salford, Manchester.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, care of Thomas Edleston, London and North Western Railway, Crewe.

1864. Hutchinson, Edward, Messrs. Pease Hutchinson and Co., Skerne Iron Works, Darlington.

1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.

1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta, India: (or care of Rev. H. M. C. Hyde, 184 The Grove, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Messrs. Hick Hargreaves and Co.'s Works, Soho Iron Works, Bolton.

1866. Ireland, William, care of J. Ireland, Edward Street, Broughton Lane, Manchester.

1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.
1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.
1858. Jaffrey, George William, Messrs. Tod and McGregor's Shipbuilding Works, Partick, Glasgow.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.
1868. James, John, Richmond Villa, Maindee, near Newport, Monmouthshire.
1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow ; and Govan.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1868. Jobson, Robert, Phœnix Works, Dudley.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, Belmont House, Starbeck, near Harrogate.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1847. Jones, Edward, The Larches, Handsworth, near Birmingham.
1857. Jones, Hodgson, 67 Victoria Street, Westminster, S.W.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1869. Keep, Alfred, Metal Sheathing Works, Coleshill Street, Birmingham.
1867. Kellett, John, 2 Newshams Buildings, King Street, Wigan.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway ; 45 Finsbury Circus, London, E.C.
1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.

1866. Kershaw, John, 24 Duke Street, Westminster, S.W.
1867. Kimball, Frederick James, 35 South Third Street, Philadelphia, Pennsylvania, United States.
1870. Kinsey, Henry, Robin Hood Engine Works, Queen's Road, Nottingham.
1865. Kirkaldy, David, Testing and Experimental Works, The Grove, Southwark Street, London, S.E.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.
1869. Koe, Stephen Lancelot, Bowling Iron Works, near Bradford, Yorkshire.
1869. Kohn, Ferdinand, 6 Robert Street, Adelphi, London, W.C.

1866. Lambert, William Blake, 3 Morden Road, Blackheath, London, S.E.
1867. Lancaster, Charles William, Gun Manufactory, 151 New Bond Street, London, W.
1863. Lancaster, John, M.P., Kirkless Hall Coal and Iron Works, near Wigan.
1870. Lancaster, Joshua, Mostyn Coal and Iron Works, Holywell, North Wales.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1870. Layborn, Daniel, Messrs. Gladstone and Wyllie's Cotton Rice and Oil Factories, Rangoon, Burmah, India: (or care of Daniel Layborn, Sen., Beverley.)
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Rhymney Iron Works, Tredegar.

1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Lloyd, Charles, 6 Westminster Chambers, Victoria Street, Westminster, S.W.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Lloyd, Joseph Foster, Darlaston Green Iron and Steel Works, near Wednesbury.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury; and Wassell Grove, near Stourbridge.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.
1862. Lloyd, Wilson, Darlaston Green Iron and Steel Works, near Wednesbury.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1869. Lockhart, Humphrey Campbell, Birmingham Plate Glass Works, Smethwick, near Birmingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
1866. Lord, Edward, Canal Street Works, Todmorden.
1859. Lord, Thomas Wilks, Bank Mills, Leeds.
1861. Low, George, St. Peter's Iron Works, Ipswich.
1854. Lynde, James Gascoigne, Town Hall, Manchester.
1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1869. Mabbutt, Thomas, Abingdon Gun Works, Shadwell Street, Birmingham.
1864. Macfarlane, Walter, Saracen Foundry, Glasgow.
1856. Mackay, John, Mount Hermon, Drogheda.
1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama.
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.
1867. Mallet, Robert, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1859. Manning, John, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Dewsbury Road, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1862. Marshall, James, 9 Coburg Street, Gateshead.
1859. Marshall, William Ebenezer, Sun Foundry, Dewsbury Road, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 56 Hagley Street, Stourbridge.
1853. Marten, Henry John, Parkfield Iron Works, near Wolverhampton.
1867. Martin, William, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.
1857. Martindale, Lt.-Colonel Ben Hay, R.E., Controller, Montreal, Canada.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
1857. Masselin, Armand, 14 Rue de Lancry, Paris.
1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1853. Mathews, William, Park Field, Great Malvern.
1847. Matthews, William Anthony, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.
1853. Maudslay, Henry, Bystock, near Exmouth. (*Life Member.*)
1864. Maudslay, Thomas Henry, 110 Westminster Bridge Road, Lambeth, London, S.E.
1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.
1869. May, George, Mining Engineer, North Hetton and Pittington Collieries, Fence Houses.
1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.
1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, 11 Commerce Chambers, Lord Street, Liverpool.
1859. Maylor, William, Calicut, Madras, India.
1847. McClean, John Robinson, M.P., 23 Great George Street, Westminster, S.W.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1867. McEwen, James, Messrs. Firmstone and McEwen, Wordsley Foundry, Stourbridge.
1864. McEwen, Lawrence Thompson, Glaisdale Iron Works, near Yarm.
1868. McKay, Benjamin, Small Arms Factory, Small Heath, near Birmingham.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, 28 Fawcett Street, Sunderland.

1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1866. Meredith, Alban, 18 Clement's Inn, Strand, London, W.C.
1867. Merryweather, Richard M., Fire Engine Works, 63 Long Acre, London, W.C.
1857. Metford, William Ellis, 26 Apsley Road, Redland, Bristol.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, Curzon Chambers, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1870. Moberley, Charles Henry, Messrs. Eastons Amos and Anderson's Works, Erith Iron Works, Erith, London, S.E.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Kingscombe, near Cowbridge.
1867. Morgans, Thomas, Mells Iron Works, near Frome.
1868. Morris, William, Waldridge Colliery, Chester-le-Street, near Fence Houses.
1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.
1865. Mosse, James Robert, Mauritius Railways, Port Louis, Mauritius.
1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1866. Muir, Andrew, Victoria Bridge Works, Salford, Manchester.
1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Sons, Vine Street, York Road, Lambeth, London, S.E.
1848. Napier, John, Messrs. Robert Napier and Sons, Engineers and Shipbuilders, Lancefield House, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1869. Nelson, James, Bonners Field Foundry, Sunderland.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.

1866. Newdigate, Albert Lewis, Byrkley Lodge, near Burton-on-Trent. (*Life Member.*)
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Sunderland Engine Works, South Dock, Sunderland.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.
1868. Norris, William Gregory, Coalbrookdale Iron Works, near Wellington, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.
1870. Nye, Henry, Messrs. Varrall Elwell and Poulot's Works, 9 Avenue Trudaine, Paris.

1868. O'Connor, Charles, Messrs. Stothert and Pitt's Works, Newark Foundry, Bath.
1866. Oliver, William, Victoria Foundry, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1870. Osborn, Samuel, Clyde Steel Works, Sheffield.
1870. Osman, Joseph, Bey, Chief Engineer and Superintendent of Factories to the Khedive of Egypt, Boulac, Cairo: 13 Conduit Street, Regent Street, London, W.
1867. Oughterson, George Blake, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.
1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.
1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.
1868. Parker, Frederick, Messrs. John Fowler and Co.'s Works, Steam Plough and Locomotive Works, Leeds.
1868. Parker, Henry, Harvey Villas, Olive Mount, Tranmere, Birkenhead.
1869. Parker, Thomas, Mersey Wheel Works, Nottingham Road, Derby.
1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1866. Parton, Thomas, Messrs. Addenbrookes Smith and Pidcock's Works, Rough Hay Furnaces, Darlaston, near Wednesbury.
1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.
1869. Peacock, Ralph, Cyclops Iron Works, Goole.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Calcutta, India.
1848. Pearson, John, 7 Old Hall Street, Liverpool.
1869. Pearson, William Hall, 50 Ann Street, Birmingham.
1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.
1866. Peele, Arthur John, Messrs. Bunnett and Co., 90 Queen Street, London, E.C.; and New Cross Works, Deptford, London, S.E.
1848. Penn, John, The Cedars, Lee, London, S.E. (*Life Member.*)
1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.
1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1869. Pickersgill, Thomas, Mining Engineer, Waterloo Main Colliery, Leeds.
1867. Pidgeon, Daniel, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.
1856. Piggott, George, King's Heath, Birmingham.
1854. Pilkington, Richard, Summerdale, Trinity Road, Birchfield, Birmingham.
1859. Pitts, Joseph, Stanningley Iron Works, near Leeds.
1859. Platt, John, M.P., Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1870. Platt, William Wilkinson, Messrs. Mather and Platt, Salford Iron Works, Manchester.
1862. Player, John, 3904 Walnut Street, Philadelphia, Pennsylvania, United States.
1869. Player, John, Clydach Foundry, near Swansea.
1866. Plum, Thomas Edward Day, Messrs. Sharp Stewart and Co.'s Works, Atlas Works, Manchester.
1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.
1860. Ponsonby, Edward Vincent, Parker Place, Broomhill, Sheffield.
1866. Porter, Charles Talbot, Allen Engine Works, Fourth Avenue, Harlem, New York, United States.
1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.
1864. Potts, Benjamin Langford Foster, 200 Camberwell Grove, London, S.E.
1851. Potts, John Thorpe, 5 Pemberton Square, Boston, Massachusetts, United States.
1867. Powell, William, Harbour Works, Douglas, Isle of Man.
1867. Pratchitt, John, Messrs. Pratchitt Blaylock and Pratchitt, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Blaylock and Pratchitt, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 37 West Sunniside, Sunderland.
1869. Purves, John, Superintending Engineer, Liverpool New York and Philadelphia Steam Ship Co., Water Street, Liverpool.
1866. Putnam, William, Darlington Forge, Darlington.

1870. Radcliffe, William, Messrs. Charles Cammell and Co.'s Works, Cyclops Steel and Iron Works, Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1862. Rake, Alfred Stansfield, St. Nicholas Buildings, Newcastle-on-Tyne.
1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1866. Ramsden, James, Abbot's Wood, Barrow-in-Furness, Lancashire.
1860. Ransome, Allen, Jun., 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1867. Ratcliff, Daniel Rowlinson, Messrs. Thomas Milner and Son, Phœnix Safe Works, Liverpool.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.
1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood, Leek, near Stoke-upon-Trent.
1865. Robinson, John, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1868. Rogers, William, Resident Engineer, Port Wakefield and Hoyles Plains Railway, Port Wakefield, near Adelaide, South Australia.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown, Ireland.
1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
1866. Rose, Thomas, Bradley Iron Works, near Bilston.
1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.
1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.
1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.
1860. Rumble, Thomas William, 6A Victoria Street, Westminster, S.W. (*Life Member.*)
1847. Russell, John Scott, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.

1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service, Stockholm, Sweden; and 19 Great George Street, Westminster, S.W.
1861. Sanderson, George Grant, Tudhoe Iron Works, near Ferryhill.
1864. Sanderson, John, Waskerley Park, near Darlington.
1869. Scarlett, James, 14 St. Ann's Square, Manchester.
1869. Schanschieff, Alexandre, Engineer, Russian Imperial Navy: (care of The Stockton Rail Mill Co., Stockton-on-Tees.)
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1865. Scott, Edward, Messrs. John Elce and Co.'s Works, Phœnix Iron Works, Jersey Street, Manchester.
1868. Scott, George Lamb, Crown Iron Works, West Gorton, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James Murray, 16 Brunswick Street, Barnsbury Road, London, N.)
1868. Scriven, Charles, Leeds Old Foundry, Marsh Lane, Leeds.
1864. Seddon, John, Wallgate, Wigan.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1867. Selby, Millin, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Atherton T. Selby, Atherton Old Hall, Leigh, near Manchester.)
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.
1867. Sharpe, Charles James, 17B Great George Street, Westminster, S.W.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1869. Sharrock, Samuel, Windsor Iron Works, Spekeland Street, Edge Hill, Liverpool.
1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.
1856. Shelley, Charles Percy Bysshe, 113 Victoria Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1847. Sinclair, Robert, 4 Westminster Chambers, Victoria Street, Westminster, S.W.
1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, Bristol.
1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.
1866. Smith, Edward Fisher, Coneygre Iron Works, Dudley Port, Dudley.
1866. Smith, Fereday, Bridgewater Offices, Manchester.

1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1866. Smith, William, Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.
1859. Sokoloff, Colonel Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.
1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1853. Spencer, Thomas, Blackladies, Brewood, near Stafford.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1869. Stabler, James, Messrs. Shand Mason and Co., Fire Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.
1869. Stenson, Foster, Burton Iron Works, Burton-on-Trent.
1868. Stenson, William Towndrow, Whitwick Colliery, Coalville, near Leicester.
1866. Stephens, John Classon, North Wall Iron Works, Dublin.
1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1867. Stevenson, Robert, Mining Engineer, Clay Cross, near Chesterfield.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1864. Stokes, James Folliott, Punjab Club, Lahore, India: (or care of Charles P. B. Shelley, 113 Victoria Street, Westminster, S.W.)

1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.

1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1870. Stubbs, Thomas, London and North Western Railway, Locomotive Department, Crewe.

1861. Sumner, William, 2 Brazenose Street, Manchester.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley.

1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.

1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.

1859. Tannett, Thomas, Victoria Foundry, Leeds.

1861. Taylor, George, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1867. Taylor, Joseph, Derwent Foundry, 99 Constitution Hill, Birmingham.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1868. Taylor, Samuel, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life*

1857. Tomlinson, Joseph, Jun., Cardiff.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1856. Tosh, George, North Lincolnshire Iron Works, Frodingham, near Brigg.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1863. Townsend, William, West Orchard, Coventry.
1865. Trow, John James, Union Foundry, Wednesbury.
1862. Troward, Charles, 8 Sussex Terrace, Camden Town, London, N.W.
1866. Turner, Frederick, St. Peter's Iron Works, Ipswich.
1867. Turner, Henry, 27 Netherfield Road North, Liverpool.
1867. Tweddell, Ralph Hart, Engine Works, Richmond Street, Sunderland.
1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.

1868. Vallance, Frederick Bevoley, Alicel Engine Works, Bridge Street, Greenwich, S.E.
1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1870. Walker, Alfred, Albion Iron Works, Aldwark, York.
1867. Walker, Benjamin, Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Liverpool.
1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.
1868. Wallis, Herbert, Midland Railway, Locomotive Department, Bradford, Yorkshire.
1865. Walpole, Thomas, Windsor Lodge, Monkstown, near Dublin.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Burton Iron Works, Burton-on-Trent.

1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.

1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.

1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.

1862. Webb, Francis William, Bolton Iron and Steel Works, Bolton.

1860. Weild, William, Gorebrook Works, Longsight, Manchester.

1862. Wells, Charles, Moxley Iron Works, near Bilston.

1862. Westmacott, Percy G. B., Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.

1867. Weston, Thomas Aldridge, care of William T. Watts, 78 Parade, Birmingham.

1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Edinburgh.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.

1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.

1862. Whitehead, William, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

1847. Whitworth, Sir Joseph, Bart., Chorlton Street, Manchester; and The Firs, Fallowfield, Manchester.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)

1868. Wigham, John Richardson, 35 Capel Street, Dublin.

1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Works, Steam Plough and Locomotive Works, Leeds.

1867. Wilkes, Gilbert, Tube Works, Bordesley Mills, Birmingham.

1867. Wilkes, John, Tube Works, Bordesley Mills, Birmingham.

1868. Wilkieson, Lt.-Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 13 Pall Mall, London, S.W.

1865. Williams, Edward, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, 37 Great George Street, Westminster, S.W.
1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.
1870. Willman, Charles, 3 Cleveland Terrace, Middlesbrough.
1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.
1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1865. Wilson, James Edwards, 23 New Street, Spring Gardens, London, S.W.
1863. Wilson, John Charles, 17 Gracechurch Street, London, E.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 4 Victoria Street, Westminster, S.W.
1865. Winby, Clifford Etches, Atlas Iron Works, Cardiff.
1867. Winby, Frederick Charles, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Old Park Iron Works, Wednesbury.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1868. Wood, Lindsay, Mining Engineer, Hetton Colliery, Hetton, near Fence Houses.
1869. Wood, Thomas James Vickers, Springfield Mill, Cleckheaton, near Normanton.
1865. Woodall, Solomon, Windmill End Boiler Works, near Dudley.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1866. Wray, William, Ship Building Yard, Burton Stather, near Brigg.
1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.
1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.
1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Liverpool.

1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin.
1847. Fairbairn, Sir William, Bart., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire Impérial des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire Impérial des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1868. Beale, Montague, 1 Great Winchester Street Buildings, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Chadwick, William, Monkbridge Iron Works, Leeds.
1848. Crosby, Samuel, Tenby House, Victoria Road, Aston, Birmingham.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.
1858. Lawton, Benjamin C., 44 Westgate Street, Newcastle-on-Tyne.

1865. Warden, Thomas, Lionel Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)
1867. Watts, William Thomas, 78 Parade, Birmingham.
1865. Whitley, Joseph, Bowman Lane, Leeds.
1870. Wright, Edwin Arthur, Messrs. Wright and North's Works, Monmore Iron Works, Wolverhampton.

GRADUATES.

1869. Bainbridge, Emerson, Sheffield and Tinsley Coal Office, Sheffield.
1869. Blake, Frederick William, Birmingham Heath Boiler Works, Birmingham.
1866. Butler, James, care of John O. Butler, Kirkstall Forge, near Leeds.
1866. Butler, Thomas Snowden, Kirkstall Forge, near Leeds.
1867. Cuss, Nevil John, Great Western Railway, Locomotive Department, Swindon.
1868. Dugard, William Henry, 77 Lower Loveday Street, Birmingham.
1869. Fenwick, Clennell, 44A Coal Exchange, Lower Thames Street, London, E.C.
1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1869. Grainger, James Nixon, Public Works Department, Chepank, Madras, India.
1867. Hill, Henry Walker, Notintone Place, Sneinton, near Nottingham.
1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.
1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.
1867. Jones, George Edward, Horseley Iron Works, Tipton.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Works, Sheaf Works, Sheffield.
1867. Mayhew, Horace, Mining Engineer, Wigan.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Hetton Colliery, Hetton, near Fence Houses.
1867. Pearson, John Edward, Spring Colliery, Ince Hall, near Wigan.
1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.
1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.
1867. Warden, Howard William, Westbourne Road, Edgbaston, Birmingham.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.
1867. Wright, John Roper, Landore Steel Works, Swansea.

PROCEEDINGS.

27 JANUARY, 1870.

The TWENTY-THIRD ANNIVERSARY MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 27th January, 1870; JOHN RAMSBOTTOM, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1870.

The Council have great pleasure, on this occasion of the Twenty-third Anniversary of the Institution, in congratulating the Members upon the present satisfactory position and the continued progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December 1869 shows a balance, after the payment of the accounts due to that date, of £5518 15*s.* 9*d.*, out of which the sum of £4500 is invested in London and North Western Railway 4 per cent. Debenture Bonds. The Finance Committee have examined and checked the receipts and payments of the Institution for last year 1869, and report that the following Balance Sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with pleasure the increase in the number of Members that has taken place during the year; the total number of

Members of all classes for the year being 855, of whom 4 are Honorary Life Members, 36 are Associates, and 23 are Graduates.

The following deceases of Members of the Institution have occurred during the past year 1869:—

WILLIAM J. W. HEATH,	India.
PETER KERR,	Paisley.
DAVID LAW,	Glasgow.
JOHN S. PERRING,	Manchester.
ANDREW SHANKS,	London.
GEORGE M. USHER,	Beverley.
THOMAS WADDINGTON,	Leeds.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year; and also of expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their Works to the Library of the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Society of Engineers; from the Society.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Journal of the Hannover Architect and Engineer's Society; from the Society.

Journal of the Saxon Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Report of the Smithsonian Institution for 1867; from the Institution.

Journal of the Royal United Service Institution; from the Institution.

Professional Papers of the Corps of Royal Engineers; from the Royal Engineer Establishment.

Professional Papers on Indian Engineering; from the Royal Engineer Establishment.

Lectures at the Royal Engineer Establishment; from the Establishment.

Proceedings of the Royal Artillery Institution; from the Institution.

Proceedings and Memoirs of the Literary and Philosophical Society of Manchester; from the Society.

Transactions of the Royal Scottish Society of Arts; from the Society.

Transactions of the Institution of Surveyors; from the Institution.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.

Reports of the Midland Steam Boiler Association; from Mr. Edward B. Marten.

Records of Steam Boiler Explosions, by Edward B. Marten; from the author.

Report of the Commissioner of Agriculture and Arts in Ontario, Canada; from the Department of Public Works.

Journal of the Society of Arts; from the Society.

The Engineer; from the Editor.

Engineering; from the Editor.

The Mechanics' Magazine; from the Editor.

The Artizan Journal; from the Editor.

The Practical Mechanic's Journal; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Steam Shipping Journal; from the Editor.

The Council have great satisfaction in referring to the number and character of the Papers that have been brought before the meetings during the past year, and the practical value and interest of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the past year:—

Address of the President.

On the further utilisation of the Waste Gas from Blast Furnaces, and the Economy of Coke due to Increased Capacity of Furnace; by Mr. Charles Cochrane.

Description of Guibal's Ventilating Fan employed at the Homer Hill Colliery, Cradley; by Mr. James S. E. Swindell.

Description of the Steam Road Roller used in Paris; by M. Gellerat.

Description of the Hydraulic Swing Bridge for the North Eastern Railway over

The Council have particular pleasure in referring to the great success and interest of the Annual Meeting of the Institution that was held in Newcastle last summer, and in expressing their special thanks to the Council and Members of the Mining Institute, and the Secretary, Mr. Theo. Wood Bunning, together with the authorities of the Literary and Philosophical Society, and the other local Members, for the very excellent arrangements and the handsome reception given to the Members on the occasion; and also their thanks to the railway authorities for the special arrangements granted for the excursions; and to the proprietors of the works that were so liberally thrown open to the inspection of the Members, for the valuable opportunity afforded to the Members for seeing their works. The Council refer particularly to the great advantage afforded to the Members in the admirable opportunity provided them for visiting the large Engineering, Shipbuilding, and Chemical Works on the Tyne, the River and Pier Works in progress of execution, and the Lead Works, Iron Works, and Collieries in the neighbourhood, together with the new Hydraulic Swing Bridge on the North Eastern Railway; and they offer their special acknowledgments to the President, Sir William Armstrong, for the great pleasure afforded to the Members by their visit to his Works, and by his exceedingly kind and hospitable reception of them at his residence at Jesmond Dene. The Council look forward with confidence to the advantages arising from these Annual Meetings of the Institution in different localities, from the facilities afforded by them for the personal communication of the Members in different districts, and from the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present Meeting for the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—mechanical firing, moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—use of injector—circulation of water.

Steam Engines—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

Blast Engines, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

MARINE ENGINES, power of engines in proportion to tonnage—different constructions of engines, double-cylinder engines, trunk engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done—steam road rollers, particulars and results.

CALORIC ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

WEAVING MACHINERY, for manufacture of different materials—improvements in looms, &c.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

WOOD-WORKING MACHINES, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

GLASS MACHINERY—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

STEAM HAMMERS, improvements in construction and application—friction hammers—air hammers.

RIVETTING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

Paper-Making and Paper-Cutting Machines, new materials and results.

Printing Machines, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto.

Fire Engines, hand and steam, ditto ditto ditto.

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto.

Cranes—steam, hydraulic, and pneumatic cranes—travelling cranes.

Lifts for raising railway wagons—hoists for warehouses—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery.

Driving Belts and Straps, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

Dynamometers, construction, application, and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

Iron Roofs, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

Fire-proof Buildings, particulars of construction—most efficient plan—results of trials.

Chimney Stacks of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

Bricks, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

Gas Works, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

Water Works, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes and construction of joints—penetration

Ships, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam power to steering.

Guns, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

Small Arms, machinery for manufacture of rifles and cartridges, &c.

Mining Operations, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone-breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

Blasting, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

Blast Furnaces, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

Puddling Furnaces, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

Heating Furnaces, best construction—consumption of fuel, and heat obtained.

Cupolas, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

Converting Furnaces, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

Smiths' Forges, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

Smiths' Fans and Fans generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

Railways, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements—engine turntables.

Signals for stations and trains, and self-acting signals.

Electric Telegraphs, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

Railway Carriages and Wagons, details of construction—proportion of dead weight.

Breaks for carriages and wagons, best construction—self-acting breaks—continuous breaks.

Buffers for carriages, &c., and station buffers—different constructions and materials.

Couplings for carriages and wagons—safety couplings.

Springs for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

Railway Wheels, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

Railway Axles, best description, form, material, and mode of manufacture.

INSTITUTION OF MECHANICAL ENGINEERS.

BALANCE SHEET.

For the year ending 31*st December* 1869.

Cr.		£	s.	d.
By Balance 31st Dec. 1868; Invested	4500 0 0			
In Bank	696 17 3	5196	17	3
„ Subscriptions from 47 Members in arrear . .		141	0	0
„ ditto from 1 Associate in arrear		3	0	0
„ ditto from 1 Graduate in arrear		2	0	0
„ ditto from 662 Members for 1869		1986	0	0
„ ditto from 30 Associates for 1869		90	0	0
„ ditto from 17 Graduates for 1869		34	0	0
„ ditto from 9 Members in advance for 1870 .		27	0	0
„ Entrance Fees from 60 New Members . . .		120	0	0
„ ditto from 1 New Associate		2	0	0
„ ditto from 2 New Graduates		2	0	0
„ ditto from 1 Graduate transferred to Member		1	0	0
„ Sale of Extra Reports		47	5	0
„ Interest; From Bank	24 1 10			
On £4500 invested at 4 per cent. from 5 Aug. 1868 to 15 July 1869, 345 days	170 7 7	194	9	5
		£7846	11	8

Dr.		£	s.	d.
To Printing and Engraving Reports of Proceedings	938 4 2			
Less Authors' copies of Papers, repaid	25 18 6	912	5	8
„ Stationery, Binding, Printing of Circulars &c. .		91	10	7
„ Office Expenses, Clerks, and Petty Disbursements		154	4	0
„ Coals, Gas, and Water		21	15	3
„ Expenses of Meetings		45	3	10
„ Fittings and Repairs		7	7	7
„ Travelling Expenses		53	14	7
„ Parcels		7	4	11
„ Postages		118	16	0
„ Salaries		794	8	0
„ Insurance		2	8	3
„ Rent and Taxes		118	17	3
Balance 31st Dec. 1869; Invested	4500 0 0			
In Bank	1018 15 9	5518	15	9
		£7846	11	8

27th January, 1870.

(Signed) SAMPSON LLOYD, WALTER MAY, } Finance Committee.

MEMOIRS

OF MEMBERS DECEASED IN 1869.

William J. W. Heath was born at Birmingham on 13th August 1835, and in 1850 was articled to Messrs. Fox and Henderson, London Works, Birmingham, for five years, during which he assisted in the superintendence of the sinking of the pneumatic cylinders for the Rochester Railway Bridge over the Medway, and also in the superintendence of railway works in Sweden. From 1857 he was engaged as assistant engineer on the Ceylon Railway, till its suspension in 1860; and in the two following years he was occupied with railway works at Lisbon. In 1863, the Ceylon Railway being resumed, he was appointed by the government on the engineering staff for its completion, which was effected in 1867. In 1868 he was appointed one of the government staff of engineers for the irrigation works in India; and in laying out near Baroon a canal from the river Soane, in connection with partner in the old firm of Messrs. Clark and Co. of Paisley, thread manufacturers. He made many improvements in various machines used in the manufacture of thread, and invented a thread-polishing machine, the success of which has been very marked. In 1869 he made another visit to the United States, for the purpose of improving the manufacture of sewing cotton; and while bathing in the sea at Longbranch, New York, was seized with cramp and drowned, on 2nd August 1869, in the fifty-second year of his age. He became a Member of the Institution in 1868.

DAVID LAW was born in 1816 at Kilsyth near Glasgow, and in 1838 became counting-house manager with Messrs. Thomas Edington and Sons, Phœnix Iron Works, Glasgow, by whom he was taken into partnership in 1844; and on the decease of the last surviving partner in 1857 he became sole proprietor of the works. At his suggestion the firm entered upon the making of cast-iron pipes, in the manufacture of which he introduced several ingenious and successful mechanical appliances; and very extensive works were erected for the purpose, from which were furnished the cast-iron pipes for many of the extensive undertakings for supplying large towns with water and with gas, including the Loch Katrine Water Works of Glasgow, the Gas Works and Water Works of St. Petersburg, and the Corporation Water Works of Dublin. He died on 26th June 1869 at the age of fifty-three. He became a Member of the Institution in 1860.

JOHN SHAE PERRING was born at Boston, Lincolnshire, on 24th January 1813; and in 1826 was articled to Mr. Robert Reynolds, the surveyor of the port of Boston, under whom he was engaged on the improvements of Boston harbour, Wainfleet haven, and outfall of the East Fen, the drainage of the Burgh and Croft marshes, and other works. In 1833 he was for a short time at Messrs. Cubitt's works in London, as a workman driving a stationary engine; and then in Mr. Newton's patent office, where he became chief draughtsman; he was afterwards foreman of the engineering department at the works of Messrs. Pontifex in London. In

1836 he was appointed engineer of the Cairo and Suez Railway, and on the abandonment of that undertaking he had charge of a short railway near Alexandria and another above Cairo, and the several engineering works of the Pasha of Egypt; he was appointed a member of the board of public works, and advised as to the embankment of the river Nile, and advocated the establishment of stations between Cairo and Suez to facilitate the overland transit to India. His chief work in Egypt was the exploration of the Pyramids, undertaken in conjunction with Colonel Howard Vyse, the results of which are published in a work called "The Pyramids of Egypt," giving the authentic details and measurements of those monuments. After travelling in Upper Egypt, Nubia, and other parts of the country, he left Egypt in 1840 and returned to England. In 1841 he became engineering superintendent of the Llanelly Railway, Docks, and Harbour; and in 1844 went to Manchester, where he was engaged upon the Manchester Bury and Rossendale Railway. On the amalgamation of this railway with other lines, forming the East Lancashire Railway, he became the resident engineer of the latter, and continued so until its amalgamation with the Lancashire and Yorkshire Railway. He was managing director of the Railway Steel and Plant Works; and at the time of his death, which occurred on 26th January 1869, the manufacture of steam engines and boilers at the engineering works established there by his father. He afterwards removed to Liverpool, and was engaged in the manufacture of metallic pistons which were then coming into general use for steam engines. In 1834 he entered the tool works of Messrs. Whitworth in Manchester; and in 1839 established himself in London in the same class of business, in which he continued till the time of his death. He acquired a very extensive practical knowledge in mechanical engineering, and a considerable part of his designs and improvements in machinery were carried out under his instructions at the works at Johnstone, where machines of large size for engineering purposes were constructed. His death took place on 11th February 1869 in the sixty-fourth year of his age, at Hastings, where he had removed after a serious accident that he had met with at Lincoln in the previous December. He became a Member of the Institution in 1850.

George Moon Usher was born at Hotham, Yorkshire, in 1828, and in 1845 entered the office of the Beverley Iron and Wagon Works, where he gradually rose to the position of secretary to the company; in this post he was highly respected and valued, and continued to hold it until his death, which took place on 29th April 1869, at the age of forty. He became a Member of the Institution in 1865.

Thomas Waddington was born on 11th December 1825 at Bradford, Yorkshire, where his father was for many years an engineer and millwright at the Union Foundry, and one of the makers of wheels and axles for the first rolling stock used on the Liverpool and Manchester Railway. After assisting his father for some years, he and his brother commenced the manufacture of all kinds of railway plant at the New Dock Works, Leeds, under the firm of Messrs. Bray, Waddington and Co. He died after a brief illness on 6th January 1869 at the age of forty-three. He became a Member of the Institution in 1856.

The PRESIDENT congratulated the Members upon the substantial and gratifying progress made by the Institution, as shown by the Report of the Council that had just been read; and he had great pleasure in moving that the Report be received and adopted, which was passed.

The PRESIDENT announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year:—

PRESIDENT.

JOHN RAMSBOTTOM,	Crewe.

VICE-PRESIDENTS.

FREDERICK J. BRAMWELL,	London.
THOMAS HAWKSLEY,	London.
SAMPSON LLOYD,	Wednesbury.
WILLIAM MENELAUS,	Merthyr Tydvil.
JOHN ROBINSON,	Manchester.
C. WILLIAM SIEMENS,	London.

COUNCIL.

CHARLES EDWARDS AMOS,	London.
JOHN ANDERSON,	Woolwich.

COUNCIL.

Members of Council remaining in office.

Edward A. Cowper,	London.
John Fernie,	Leeds.
Sir Charles Fox,	London.
Walter May,	Birmingham.
W. Montgomerie Neilson,	Glasgow.
Charles P. Stewart,	Manchester.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

TREASURER.

Henry Edmunds,	Birmingham.

SECRETARY.

William P. Marshall,	Birmingham.

ASSISTANT SECRETARY.

Alfred Bache,	Birmingham.

The following New Members were also elected :—

MEMBERS.

Thomas Barber, Jun.,	Nottingham.
Arthur Barclay,	Reigate.
James Wilkie Dunlop,	London.
Henry Tanner Ferguson,	Redruth.
Arthur Samuel Hamand,	Birmingham.
Petronius Hodges,	Penistone.
William Henry Hunstone,	Manchester.
John P. Jackson,	Clay Cross.
John Lennox Kincaid Jamieson,	Glasgow.
Edward James Leonard,	London.
Charles Henry Moberley,	London.
James Murdoch Napier,	London.
William Wilkinson Platt,	Manchester.
Alfred Walker,	York.
Charles Willman,	Middlesbrough.

The adjourned discussion was then resumed upon the paper read at the previous meeting of the Institution in November 1869, "On Le Chatelier's plan of using Counter-pressure Steam as a Break in Locomotive Engines," by Mr. C. William Siemens, of London.

ON LE CHATELIER'S PLAN OF USING COUNTER-PRESSURE STEAM AS A BREAK IN LOCOMOTIVE ENGINES.

By Mr. C. WILLIAM SIEMENS, of London.

(*Read at the Meeting on 4th November*, 1869.)

In the working of Locomotive Engines, the valve-gear is sometimes reversed in cases of urgent necessity, while still continuing to run forwards, in order to obtain in an emergency the retarding effect of the full boiler pressure opposing the motion of the pistons, for the purpose of stopping the train in a shorter space than could be effected by means of the breaks alone. The reversed working however cannot be continued longer than a few minutes in ordinary locomotives without serious injury to the engine, owing to the heating of the cylinders and the cutting of the rubbing surfaces from want of lubrication: the cylinders act as pumps in the reversed working, drawing in the heated gases from the smokebox, and forcing them into the boiler through the regulator which continues open; their action is thus the reverse of the ordinary action, when they receive steam from the boiler and discharge it into the smokebox. The object of the plan described in the present paper is to enable locomotives, in taking trains down inclines, to be worked continuously for any length of time with the valve-gear reversed, so as to obtain the advantage of the counter-pressure steam as a retarding power, instead of the train breaks, without involving the objections hitherto preventing the use of continuous reversed working.

In the accompanying diagrams, Figs. 6 and 7, Plate 3, the ordinary action of the steam in the cylinder in the regular working of locomotives, not reversed, is represented in Fig. 6; and the corresponding action when the valve-gear is reversed while still running forwards is illustrated in Fig. 7. The slide-valve in both cases is working at the same degree of expansion, cutting off or closing the port from the boiler at half stroke. In the ordinary working, Fig. 6, the piston in its forward stroke is propelled by the full pressure of steam from the boiler during the first portion of the stroke from A to B, until the steam is cut off at B by the slide-valve; and the pressure is then diminished by expansion of the steam from the point of cut-off B, and more rapidly towards the end of the stroke by the opening of the exhaust port at C. But in the reversed working, Fig. 7, the distribution of steam is effected by the slide-valve in the inverse order and on the opposite side of the piston, while the motion of the piston and driving wheels still continues in the same direction as previously; the difference therefore of the reversed indicator diagram from the ordinary indicator diagram is only that the relative positions of the several points A B C D of the distribution are reversed, whilst the direction of motion of the piston continues the same in both diagrams. In the reversed working accordingly the cylinder remains open to the atmosphere in front of the piston through the exhaust port, during the first portion of the stroke from D to C; and the contents of the cylinder are then compressed from C to B in consequence of the closing of the exhaust port at C; after which the steam port opens at B, admitting the steam at full boiler pressure to oppose the motion of the piston throughout the concluding portion of the stroke from B to A. In the return stroke, in ordinary working, the steam in front of the piston escapes into the atmosphere during the greater part of the stroke, D to E, Fig. 6, until the exhaust port closes at E at nearly the end of the stroke; the steam remaining is then compressed in the end of the cylinder from E to A, and opposes during its compression the motion of the piston. But in the reversed working, Fig. 7, the return stroke begins at A with the full pressure of steam filling the clearance at the end of the cylinder behind the piston, and this steam propels the piston by its expansion until the exhaust port opens at E; the cylinder then continuing open to the exhaust during the remainder of the stroke from E to D, the piston draws in the heated gases from the smokebox, and in the succeeding forward stroke the contents of the cylinder are compressed as soon as the exhaust port closes again at C, and are forced by the piston into the boiler against the full pressure of steam. The latter portion of each stroke of the piston is thus made against the full boiler pressure, which resists the motion of the piston and consequently acts as a powerful retarding force to check the rotation of the wheels in the direction of running.

In the ordinary working, Fig. 6, although there is a free exhaust, the pressure of the exhaust steam escaping from the cylinder from D to E is above the atmosphere, on account of the frictional resistance of the exhaust port and blast-pipe. Similarly in the reversed working, Fig. 7, the pressure in front of the piston rises above the boiler pressure previous to the end of the stroke at A, on account of the frictional resistance of the steam port and steam pipe. The steam pressure during the first part of the stroke from A to B in the ordinary working, Fig. 6, is for the same reason lower than the boiler pressure: the extent of difference in each case depending upon the speed of the piston.

The result of the reversed working is consequently that at each stroke of the pistons, or four times during each revolution of the wheels, a certain quantity of the heated gases from the smokebox is pumped into the boiler. These gases, consisting of the products of combustion mixed with the unconsumed atmospheric air, are at a high temperature, generally about 500° to 600° Fahr.; and the consequence is a rapid heating of the cylinders, to so serious an extent as to cause cutting of the rubbing surfaces, owing to the drying up of the lubrication and the burning of the stuffing-box packings, if the reversed working of the engine is continued for more than a few minutes. Another important source of heat in the reversed working is the compression of the gases in the cylinder from C to B, Fig. 7, on the closing of the exhaust port at C, and their subsequent compression to the boiler pressure when mixed with the admitted steam; the heat thus developed is the equivalent of the mechanical work done in arresting the motion of the engine by the resisting pressure against the pistons, the consequent absorption of mechanical force causing a corresponding generation of heat; and this conversion of work into heat forms an interesting illustration of thermo-dynamic action.

The plan of counter-pressure working which forms the subject of the present paper is a simple and efficient mode devised by M. Le Chatelier, Ingénieur-en-Chef des Mines, for removing the difficulties experienced in working engines reversed, so as to allow of the reversed working being continued for any desired length of time without difficulty, and without incurring any risk of injury to the engine. This plan has proved thoroughly successful in practice, as an additional break power of great service in descending long inclines, where it can be readily applied and kept in action for any required distance without any difficulty or practical objection; and it has now come into extensive use on the Continent. It has the important advantage of rendering the great weight of the engine available as break power, without incurring the serious objection attending the application of ordinary breaks to engine wheels from the heating of the tyres and their consequent tendency to become loosened. In the counter-pressure working the engine wheels are not stopped or made to skid on the rails, but a steady retarding force is continuously applied to them within the limit of their adhesion; for the total amount of retarding power obtained from the counter-pressure steam against the pistons when running reversed is generally less than the total amount of propelling power of the steam in ordinary working with the same boiler pressure, as shown by the smaller area of the reversed diagram, Fig. 7, in comparison with that of the ordinary diagram, Fig. 6. The wear of rails and tyres that is caused by the friction of the train wheels when skidded by the ordinary breaks, and the consequent injury to the wheels by wearing flat places in their circumference, are avoided to the extent that the counter-pressure steam is used as a break on the engine; and the practical working of the counter-pressure plan has been found so satisfactory, that its use has even been carried so far in many cases as to supersede the employment of the train breaks, not only in descending inclines, but also in stopping and shunting at stations, thereby saving altogether the ordinary wear of the wheel tyres and rails.

The counter-pressure plan of working consists simply in injecting into the cylinders, whilst working reversed, a certain quantity of heated water or mixed water and steam from the boiler, sufficient to fill the cylinders to the exclusion of the smokebox gases. The injected water being in the form of a spray or fog becomes converted into steam by contact with the heated metal of the cylinders, which is reheated at each stroke; and the reversed working of the engine consequently pumps back only steam into the boiler, instead of the gases from the smokebox. This is an important point when the boiler is fed by injectors, as their action is liable to be interfered with by the presence of air or fixed gases in the boiler.

The apparatus for working with the counter-pressure steam is shown in Figs. 1 to 4, Plates 1 and 2, and consists simply of a pipe A, 1 to 1¼ inch diameter, supplying continuously a small jet of water from the boiler into the base of the blast pipe B near the cylinders, with an orifice of 1-60th to 1-40th square inch area, and delivering from 10 to 50 lbs. of water per minute. This water being supplied at the temperature of the boiler flashes into a mixture of steam and water immediately on escaping from the nozzle into the atmospheric pressure of the blast pipe; the exhaust passages are thus filled with watery vapour, which is drawn into the cylinders by the reversed working of the pistons; and this vapour becomes completely converted into steam in the cylinders, by the heat which is accumulated in the metal of the cylinders, in consequence both of the compression of their contents and of the entrance of hot steam from the boiler during a part of each stroke. The quantity of water injected is regulated by a cock C, Fig. 4, upon the jet pipe, and the correct quantity is readily judged of by the enginedriver: a sufficient quantity is supplied to produce an excess of watery vapour in the blast pipe, and consequently a constant discharge from it similar to the discharge in ordinary working; while on the other hand too large an excess of injection is shown at once by the discharge of water from the chimney like priming.

In the case of inside-cylinder engines, a single injection-nozzle is inserted in the base of the blast pipe: but in outside-cylinder engines having two branches to the blast pipe, the injection pipe is forked, as shown in Fig. 2, and a separate nozzle is inserted in each branch of the blast pipe. In this case it is important to have the forking of the injection pipe made quite symmetrical, so as to lead an equal quantity of the injection water to each nozzle; and a brass junction piece is inserted at the fork of the injection pipe for this purpose, as shown to a larger scale in Fig. 3. It is desirable as far as practicable to give the injection pipe a continuous fall, in order to prevent any accumulation of water in the pipe.

In some cases the introduction of the injection has been made direct into the exhaust port close to the slide-valve; and this position has the advantage of reducing the quantity of discharge from the blast pipe. But when the injection cock is properly arranged, so as to give the means of readily regulating the quantity of injection with sufficient delicacy, the introduction of the jet at the base of the blast pipe as near the cylinders as it can conveniently be fixed is found quite satisfactory. The injection cock being made with a long traverse for the limits of injection required, as shown in Fig. 5, the enginedriver can easily avoid an excess of injection water, and can regulate the quantity according to the point of cut-off of the valve-gear and the speed of running, judging by the appearance of the steam-cloud issuing from the chimney.

In the first experiments upon the plan of working with counter-pressure steam, carried out under the direction of M. Le Chatelier upon the Northern of Spain Railway, of which he was "Directeur," the injection of a mixture of water and steam was used, by having two pipes from the boiler, one from the water space and the other from the steam space, as shown in Fig. 4, the two uniting before reaching the injection nozzle. The fixed proportions of water and steam were regulated by a cock in each pipe, the two cocks being coupled together in that instance by a rod. This plan of employing a mixture of water and steam was long in use on the Northern of Spain Railway, where a number of engines have been working for more than two years with this apparatus; the resident authorities on that railway had the opinion that a large mixture of steam was quite necessary for the satisfactory working of the plan. Subsequently the engineers of the French railways proved by practical trials in working that it is necessary for complete success to employ a large proportion of water; but it has been found by M. Le Chatelier in France that an injection of water alone, according to his original recommendation, is quite sufficient and satisfactory, and he considers that this is preferable in action to any mixture of water and steam. The jet of water alone has also the important practical advantage of simplicity in construction and management, as there is then only the water injection cock to open for putting the plan into operation, and the required degree of opening is readily adjusted by simply observing the discharge of vapour from the chimney.

The use of water injection alone is now extensively adopted, and there are a large number of engines working regularly on the French railways upon this plan. The jet of water completely answers all the purposes required, absorbing the heat developed in the cylinders by compression, supplying lubrication in the cylinders to prevent any risk of cutting, and filling the blast pipe continuously with vapour or spray so as to prevent any entrance of the smokebox gases into the cylinders; and these results are attained with a less loss from the boiler than when a jet of steam is employed for the purpose in combination with the water. The water jet issuing from the boiler at a temperature of about 340° Fahr. into the atmospheric pressure in the blast pipe gives off instantly a quantity of steam at atmospheric pressure, and becomes a mixture of steam and water at 212° Fahr., forming a watery vapour that contains usually about 86 per cent. of water by weight but less than $\frac{1}{2}$ per cent. (0·4) of water by volume; the discharge is similar to that which takes place when a tube bursts in the boiler or when the boiler is blown off. The volume of water contained in this vapour being less than $\frac{1}{2}$ per cent., is so small that it passes freely through the ports and into the cylinders with the steam; and no inconvenience can be caused by the water mixed with the steam whilst it passes through with such rapidity that it has not time to be deposited and to accumulate in the bottom of the cylinder. When the injection of water into the exhaust passages of locomotives was first proposed by M. Le Chatelier, the fear was expressed that it would be objectionable in practice, on account of the difficulty experienced in ordinary working from occasional accumulation of water in the cylinders, which is attended with the risk of breaking the cylinder covers; and there was consequently a delay in carrying out the complete plan of injecting water alone, until M. Le Chatelier was enabled to attend personally to the working out of his plan. The apprehension of any such difficulty has now however been proved to be quite unfounded; and no practical objection is experienced in the regular working of engines with the water injection.

Counter-pressure working is found to be more conveniently effected with the screw reversing gear D, Fig. 4, than with the reversing lever, as the screw gear admits of bringing the counter-pressure into action more gradually, and shifting the valve-gear backwards more steadily and holding it in any position more securely than can be done with the reversing lever and catch-plate. With the screw gear the engine is readily reversed for applying the counter-pressure, whilst leaving the steam regulator open, and the valve-gear is adjusted to the right point for descending steep gradients or for stopping trains at stations. The screw reversing gear is more particularly necessary where a mixed steam and water injection is used, because the slide-valves having a tendency then to get hot and seize might jerk the ordinary lever out of position by a sudden strain, and the screw is therefore required for holding the reversing gear secure in all positions; but with the simple water injection the ordinary reversing lever constructed to stand forward in forward gear is found quite sufficient in practice, because the valves are kept well lubricated with the water injection. As the whole apparatus then required for the counter-pressure plan consists only of a single cock and pipe, it can be readily applied to any existing engine without in the least interfering with the convenience of working. The simple water injection involves no objection of complicating the driver's work or adding to the repairs of the engine; the only thing required to be done by the driver is to open the injection cock at the time of reversing the engine, and adjust it so as to keep up a light cloud of steam from the chimney without any excess of water.

The portion of the cylinder that has to be filled up at each stroke of the piston by vapour drawn in from the blast pipe when working reversed is the space from F to C, Fig. 7, comprised between that point F of the stroke at which the steam originally filling the clearance at the end of the cylinder has expanded down to atmospheric pressure, and the point C at which the communication with the blast pipe is closed by the exhaust-port shutting in the return stroke. On calculating the capacity of this portion of the cylinder under the most extreme circumstances of counter-pressure working, it is found that the quantity of steam alone required to fill the cylinders and prevent the entrance of the smokebox gases amounts in weight to about 55 lbs. per minute; and one third of this quantity is found to be sufficient for taking up the heat liberated in the cylinders. This quantity is suitable for a large goods engine running at a speed of 26 miles per hour with 4 feet wheels, which is equivalent to 720 cylinders full per minute; and the quantity of vapour to be supplied per cylinder full is consequently only about 1 oz. (0·077 lb.) The mixture of water and steam at 212° Fahr. from the jet comes in contact in the cylinder with a mass of metal weighing as much as 2600 lbs. and at a temperature between 212° and 340° Fahr.; then taking the specific heat of the metal at 0·12, and estimating the quantity of heat required to convert into steam at 212° the 86 per cent. of water contained in the 1 oz. of watery vapour (at the rate of 966° Fahr. for 1 lb. of water), a reduction in temperature of only $\frac{1}{5}$° Fahr. (0·20°) in the mass of metal would be sufficient to supply all the heat required for evaporating the water introduced into the cylinder at each stroke:—

$$\frac{0{\cdot}86 \times 0{\cdot}077 \text{ lb.} \times 966^\circ}{2600 \text{ lbs.} \times 0{\cdot}12} = 0{\cdot}20^\circ \text{ Fahr.}$$

The combined effect therefore of the heat liberated in the cylinder by the reversed action of the engine, together with that communicated through the metal from the high-pressure steam in the steam-chest, is that with water injection alone a supply of steam is maintained fully sufficient for filling up the cylinder at each stroke, and for keeping up a constant discharge from the blast pipe so as to prevent any entrance of the smokebox gases.

As the lubrication of the pistons and slide-valves is dependent mainly upon the water always present with the steam in ordinary working, it is important when working under counter-pressure that the vapour drawn into the cylinders should contain an excess of water beyond the quantity required to be evaporated by the surplus heat in the cylinders, so as to ensure sufficient moisture being left in the steam for the purpose of lubrication. This object is best attained by the use of water injection alone; and the water injection is thus found to fulfil the requirements both of supplying the necessary quantity of steam and also of providing completely for the lubrication.

The amount of heating effect caused by the compression that takes place in the cylinders when running reversed has been ascertained by experiments on the Northern of France Railway, in which two engines were coupled back to back on a level part of the line, one running forwards, and dragging the other engine reversed against the resistance of the counter-pressure steam. At a speed of 18 miles an hour, without either water or steam injection, it was found that the stuffing-box packings of the reversed engine took fire after a run of less than 2 miles, although the blast-pipe was closed to avoid drawing in the hot smokebox gases, and a separate opening was made for drawing in fresh air from the outside. After renewing the packings, a jet of steam in excess was injected into the blast-pipe, and the packings then took fire after a run of between 3 and 4 miles. But with a mixed injection containing a large proportion of water, a run of 18 miles was made, without the slightest injury. Under the usual conditions of working, when the hot smokebox gases would be drawn into the cylinders in running reversed, the engine would be so much injured in a few minutes as to be rendered unfit for work; but when working reversed with the water injection, there is not the slightest injurious action, however long the reversed working may be continued, or however great the speed of running: the packings of the stuffing-boxes continue in good order, and the piston-rods do not even become dry.

Various modifications in the arrangement for counter-pressure working have been used and thought to be advantageous under the different circumstances of the engines to which the plan has been applied. For large goods engines with all the wheels coupled, working heavy trains down moderate inclines or taking moderate trains down heavy gradients, and consequently working mainly in full gear, a water injection is applied for regular use when running with the counter-pressure steam; and in addition a separate steam jet is also applied, discharging into the water injection tube, which is found advantageous for occasional use when the pressure falls low in the boiler and the due proportion of steam in the jet consequently falls short. The separate steam jet is also of service in starting the counter-pressure working at the moment of beginning to descend an incline, and for clearing the passages of water at the moment the train is stopping. In passenger engines, where the use of counter-pressure steam is mainly for the purpose of an extra break in cases of emergency and for stopping at stations, a combined injection of water and steam may be used with advantage, a cock being provided for each injection, but both worked from the same handle and adjusted so that the water supply is always about half of the steam, the total supply of water and steam together being about 30 to 40 lbs. per minute. Experience however shows more and more definitely that the addition of a steam jet is not absolutely necessary, and that the simple water jet alone is really sufficient for all purposes; and this plan has an important advantage in simplicity, as there is then only the water cock to attend to at the time of reversing the engine, for putting the counter-pressure working into operation. This arrangement is consequently the one now recommended by M. Le Chatelier for general application in counter-pressure working.

The most extensive application that has at present been made of the counter-pressure working is on the Paris and Lyons Railway, on which 1400 engines are using it in the regular work of descending inclines, and in stopping and shunting at stations. These engines are fitted with a very complete apparatus for the purpose, designed by the engineer of the line, M. Marié; it is made with two small slide-valves worked by screw handles, one for regulating the water injection and the other the steam. On the Paris and Orleans Railway the injection of water alone has been exclusively adopted. The engineer of this line, M. Forquenot, employs a small conical valve with a long cone and a screw handle for regulating the water jet, as shown in Fig. 5. The water injection alone is found entirely satisfactory; and where a jet of steam is also used, experience seems to show more and more that the steam jet may be altogether dispensed with. With the use of water alone there is a saving in the quantity of vapour discharged from the blast pipe, as this can be regulated down to the lowest quantity sufficient for preventing the smokebox gases from entering; but when a mixture of steam and water is used, a considerable portion of the steam necessarily escapes direct from the blast pipe. An actual saving in the total quantity of water taken from the boiler is also found in practice, when water injection alone is used, because the correct quantity can be more uniformly regulated in that case so as to avoid any undue excess of water: the discharge from the chimney, by which the driver judges how to regulate the supply, is very visible in the case of water injection, being then in the state of a moist cloud; but with mixed steam and water injection, the discharge from the chimney is so much drier that the supply of injection is liable to become considerably in excess before sufficient indication is afforded by the appearance at the chimney top.

The steam regulator is kept open throughout the reversed working; but the total amount of retarding effect produced by the counter-pressure steam can be regulated to any extent by shifting the valve-gear into the positions for different degrees of expansion. The earlier the point of cut-off for the steam in ordinary working, the later will be the point of admitting the counter-pressure steam in reversed working; and the smaller consequently will be the total amount of the retarding effect upon the piston. In Fig. 8 is shown a counter-pressure diagram with a cut-off at 32 per cent. of the stroke, taken at the speed of 18 miles an hour, the shaded area giving the total amount of retarding power in that case.

The total amount of retarding power that can be obtained in the reversed working is in all ordinary cases less than the propelling power in the regular working when not reversed; and the proportion of the retarding power does not usually exceed about 60 per cent. ot the propelling power in the case of the fullest steam admission. This difference is owing to the amount of forward pressure necessarily received in the reversed working from the expanding steam in the end of the cylinder, propelling the piston at the beginning of each stroke from A to F, Fig. 7, and the loss of retarding effect at the other end of the stroke from D to C during the time that the cylinder is in free communication with the atmosphere through the open exhaust port. As the break power of the engine however is limited by the adhesion of the wheels, and it is important to keep within the limit of slipping of the wheels, in order to avoid the wear and heating of the tyres, the above proportion of 60 per cent. of the propelling power proves quite sufficient as the maximum break power available by counter-pressure working.

The principal application of counter-pressure working is for moderating the speed of trains down steep inclines, on which breaks are ordinarily required to be in constant action throughout the descent. In the ascent of the incline the engine has to overcome the friction of the train in addition to the resistance of gravity, but in the descent the retarding force required from the engine is only the difference of these; consequently when the retarding power of the engine amounts to 60 per cent. of its propelling power, the engine will be able to take down the incline the same weight of train that it can take up, provided that the gradient is such that the one of these resistances is 60 per cent. of the other, or the difference between the resistance of gravity and the friction of the train is 60 per cent. of the sum of those two resistances. This gradient is about 1 in 27; and therefore upon all lower gradients than 1 in 27 an engine working with counter-pressure steam can take down without the use of the breaks a heavier train than it can take up. Engines intended to be frequently worked down inclines can have the valve-gear permanently modified in adjustment, so as to give less lead to the valve when working reversed, and a greater proportionate retarding effect. In France, where an extra large size of cylinders is generally adopted, for the purpose of working expansively with the maximum loads, the proportion of available retarding power in counter-pressure working becomes increased beyond the above 60 per cent., and probably in many cases is but little below the actual traction power.

The use of counter-pressure steam has now become general in France, in all the districts of heavy inclines, and the trains are regularly taken down the inclines by the control of the engine alone, without any of the train breaks or the tender break being used, except in case of an excessive load. There are inclines of 1 in 67 worked in this manner in a great many places, one of 1 in 50 at Pontarlier, 1 in 39 at Tarare, 1 in 33 on the Cantal Hill in Auvergne, and 1 in 31 at Lannemezan. Also in Spain, Switzerland, Italy, and Austria, the plan is extensively adopted. An important advantage in safety is obtained from the counter-pressure plan of working, on account of the complete uniformity of speed that can be maintained by the enginedriver; this is effected without requiring any exceptional attention, and the speed can be regulated with as much or even more facility than in ordinary running forwards.

In working steep inclines by the counter-pressure steam instead of the ordinary breaks, a marked saving has been found in the wear of the rails and tyres, in consequence of the grinding action of the skidded wheels being avoided. On the Lannemezan incline of 1 in 31 for 6¾ miles length on the Southern of France Railway, where the extra wear upon the descending line was so severe that it was intended to substitute steel rails, it was found after the general adoption of the counter-pressure working that the cause of inequality in wear had been entirely removed, and the rails were worn no more rapidly upon the descending line than upon the ascending one; and the steel rails which had been procured were therefore employed elsewhere.

The use of counter-pressure steam as a break has the important advantage that it can be brought into action instantaneously when required in any emergency, three or four seconds being sufficient for reversing from full forward gear to full backward gear and turning on the water injection, the regulator remaining open throughout; whereas with ordinary breaks the enginedriver has to signal to the breaksman by whistle. Moreover the efficiency of the engine as a break is greater than that of an equal weight of break vans, because their wheels offer less resistance when skidded, than the adhesion of the engine wheels when the power applied is not sufficient to make them slip.

An objection might be thought to apply to the working of inclines with the retarding power entirely at the head of the train, instead of mainly at the tail of the train in the ordinary break vans: more particularly in consideration of the lateral pressure thereby caused in passing round sharp curves upon the incline. But in practice this mode of working has not been found to be attended with any objection; and it has to be borne in mind that in descending an incline with the retarding power of the engine alone, which is entirely under the easy control of the driver, a much greater uniformity of speed is maintained than is possible with the ordinary breaks worked by different men separated from one another; and the variations in lateral pressure that arise with the ordinary breaks from varying centrifugal force in the curves are therefore avoided. An important advantage in safety applies to the plan of controlling the speed of the train by the engine alone, as the retarding power of the engine is not only more prompt and efficient than the train breaks, but it can be more relied upon for being always ready to be brought instantly into full action. Nothing can interfere with its efficient operation but the exceptional occurrence of a breakage in the working gear of the engine, or the bursting of a boiler tube; and in any such case all the ordinary train and tender break power is still available for use.

Practically it may be considered that the employment of counter-pressure steam in the engine is equivalent to as many ten-ton break vans in the train as there are pairs of coupled wheels in the engine; and the whole of this retarding power is controlled and applied at once by the enginedriver with the greatest facility, and without having to communicate with any one else. It is found an advantage for the plan to be habitually employed in regular working for stopping the trains at stations, without any use of the train breaks and with only occasional use of the tender break as an auxiliary. By this means not only are greater promptness and accuracy obtained in the stopping at stations, but the constant employment of the counter-pressure working ensures its being always ready for instant use in any emergency. In case of accident a great additional break power is available in the train breaks, and these being only called for by whistle signal in cases of emergency would be likely to be applied with the more energy from not being in use for ordinary stoppages. In France the counter-pressure steam is frequently employed for the ordinary stoppages, instead of using the breaks; but this plan is not regularly adopted at present, except on the Paris and Lyons Railway. Those enginedrivers however who are accustomed to the regular use of the counter-pressure steam for taking trains down inclines, generally make great use of it for stopping at stations, and often without using the train breaks at all; and the shunting at stations is done simply by the reversing handle, leaving the regulator open, and without the use of the breaks.

In conclusion it may be observed that, notwithstanding the important advantages obtained from the plan of counter-pressure working, and the complete practical success of its application upon the Continent, it has not yet been introduced into this country, probably from the circumstance of not having been brought sufficiently under the notice of railway engineers; and the writer feels it a privilege to be instrumental in supplying this deficiency, by bringing the subject in the present paper before the Institution of Mechanical Engineers, on behalf of his esteemed friend M. Le Chatelier. The simplicity and importance of this plan are such, that it requires only to be fully known in order to be highly appreciated; and the invention has been liberally thrown open to general use by M. Le Chatelier, whose aim has been only to effect a desirable object of great practical utility.

(*Discussion at the Meeting on 4th November*, 1869.)

Mr. Siemens thought the facts which had been adduced in the paper, with regard to the practical results of the counter-pressure system in actual working, were sufficient to prove that there was a great deal of advantage to be gained from the adoption of the plan. Mechanically speaking, the apparatus employed was the very simplest possible, consisting only of a water pipe fitted with a regulating cock; but the working out of the plan to a successful application in practice had required a great amount of careful experiment and forethought. A plan of introducing air into the cylinders when running reversed had previously been proposed by Mr. De Bergue, but had been abandoned after trial, because it was found the heat developed in the compression of the air was so great as to cause cutting in the cylinders. When M. Le Chatelier's plan of using a mixture of steam and water was first proposed, an objection was felt by most engineers to introducing any water into the cylinders; and the early trials of the plan were therefore made with steam alone. At first sight indeed it might seem that steam alone ought to be sufficient for all that was required, inasmuch as the steam after expanding into atmospheric steam in the exhaust-pipe would be at the temperature of 212° Fahr., and in compressing this steam to the boiler pressure in the reversed working it might be supposed that its temperature would rise only to the temperature of saturated steam at the boiler pressure, which would be about 340° Fahr. for a pressure of eight atmospheres or 120 lbs. per square inch. Such a conclusion however would be very erroneous; for although it was the fact that steam expanding behind the piston in a working cylinder became partially condensed, owing to the abstraction of the heat that was converted into the work done, yet the expansion of the same steam in the same cylinder when not doing any work was not attended with any condensation, but on the contrary the steam became superheated in the latter portion of the stroke, on account of the greater total quantity of heat in high-pressure steam than in low-pressure. This property of steam when expanding without doing work had been shown in a paper that he had read at a former meeting of the Institution (see Proceedings Inst. M. E. June 1852); and the consequence was that, when a jet of steam alone was used in the counter-pressure working, the high-pressure steam expanding into atmospheric pressure without doing any work became superheated to an extent quite sufficient to be detrimental to the cylinders and packings; and when this superheated steam was compressed up to the boiler pressure in the return stroke, it would become still more highly superheated, and the result would be the rapid destruction of the rubbing surface of the cylinder. On this account the introduction of water with the steam was rendered necessary in the reversed working; and it had been shown in the paper now read that water alone, introduced from the boiler into the exhaust-pipe, was sufficient, because on issuing into the atmospheric pressure of the exhaust-pipe the jet of water instantly flashed into a fog of mixed steam and water, containing by volume only about $\frac{1}{2}$ per cent. of water, which however had sufficient refrigerating effect to keep the steam in the cylinder always down to the temperature of saturation, and thereby to prevent any injurious effect from superheating. The practical management of this plan of counter-pressure working was extremely simple, the enginedriver having only to turn on the water injection until the appearance of a slight cloud of steam at the chimney top, which showed that there was just a little more water injected than was absolutely necessary. The reversed working of the engine thus gave a break power of great efficiency, and the inertia of the train was converted into heat stored up in the boiler, instead of being uselessly expended in grinding the rails and destroying the tyres. He understood a trial of the plan had just been made upon a heavy goods engine on the Midland Railway near London, and had been attended with complete success.

The CHAIRMAN (Mr. Ramsbottom) considered the subject was one of the greatest interest and importance in the working of railways, and proposed the adjournment of the discussion to the next meeting; and he hoped that before then some further trials of the counter-pressure system would be made upon lines in this country.

He moved a vote of thanks to Mr. Siemens for the paper, which was passed; and the discussion was adjourned to the next meeting.

(Discussion at the Meeting on 27th January, 1870.)

Mr. SIEMENS observed that the very ingenious plan of counter-pressure working, which had been described in the paper read at the last meeting, might be summed up as consisting simply in an arrangement for delivering a jet of hot water from the boiler into the exhaust-pipe of a locomotive engine, at the time when the engine was required no longer to propel the train forwards but to retard its motion, as in stopping at a station or going down an incline, or on any other occasion when the momentum of the train was required to be absorbed. Instead of the ordinary practice of applying the tender break under such circumstances, it was simply necessary in the counter-pressure working to reverse the link motion and turn on the water jet, leaving the regulator always wide open, so as to obtain the retarding effect of the full boiler pressure resisting the rotation of the wheels in the direction of running. The jet of water being delivered at the boiler temperature of about 340° Fahr. into the atmospheric pressure of the exhaust-pipe, flashed instantly into a spray or fog of mixed steam and water; and although at first sight it might be supposed that the water would greatly predominate in the mixture, this was not actually the case, as calculation showed that only $\frac{1}{2}$ per cent. of the volume of vapour was in the form of water, all the rest being steam at atmospheric pressure. This mixture of steam and water being drawn into the cylinders by the pistons, owing to the reversed action of the valve-gear, became compressed by the pistons in their return stroke; and this compression converted into steam a certain portion of the $\frac{1}{2}$ per cent. of water, being the equivalent, according to the dynamical theory of heat, of the retarding force obtained. The cylinders thus became steam generators or heat producers in the reversed working; and the steam contained in them being forced back by the pistons into the boiler, the heat developed by arresting the motion of the train was stored up in the boiler; and the plan was thus, dynamically speaking, a very perfect arrangement for utilising in the form of heat the momentum of the retarded train.

The application of this counter-pressure system had now become very extensive both in France and Germany, and there were at the present time more than three thousand locomotives fitted with this simple apparatus, the employment of which was more and more extended to the regular working of the engines as the men became more accustomed to its use. It was always used in taking trains down steep inclines, and also very extensively for stopping at stations and for shunting, the regulator being left full open all the time, and the retarding or stopping being effected entirely by the reversing handle. A further application of the steam jet in the exhaust-pipe had been communicated to him by M. Le Chatelier as having been recently carried out upon the Paris and Orleans Railway, for the case of running down inclines where the gradient was such that the speed of the descending train was just about maintained by gravity, without requiring either propelling or retarding power to be exerted by the engine. This was the case with passenger trains on gradients of about 1 in 110 to 1 in 90, and with goods trains on 1 in 250 to 1 in 200; and as the action of the counter-pressure steam was not required under such circumstances, the regulator was then kept closed. The steam jet was turned on in these cases, without reversing the engine, and was kept on during the descent of the incline, by which means a constant supply of moist steam at atmospheric pressure was maintained in the cylinders and valve-chests, keeping the rubbing surfaces constantly lubricated, without exerting either a propelling or a retarding effect upon the pistons.

Since the paper was read at the last meeting, previous to which time no application of the counter-pressure system had yet been carried out in England, he was happy to find that trials of the plan had been made on the London and North Western, Midland, and South Western Railways; and the subject was one which he thought was deserving of serious attention on the part of the railway engineers in this country.

Mr. F. J. Bramwell said he had had an opportunity very recently of making some experiments upon the South Western

Railway with an engine fitted with the counter-pressure apparatus described in the paper. The trial was made on the Windsor branch, between Staines and Wrasbury stations, where the line was straight and level; the day was fine, and the rails in first-rate order for break action; the wind was rather fresh on one side, and slightly in the direction of the running. The engine was a six-wheeled one, with four wheels coupled; it had outside cylinders 17 inches diameter by 22 inches stroke, and the driving wheels were 6 ft. 6 ins. diameter; the slide-valves were balanced valves of very good construction, admitting of reversal with the greatest ease whilst running at full speed and with full steam on. The weight of the engine in running order, without the tender, was 31¾ tons, of which 21¼ tons were upon the coupled wheels; and the total weight of the entire train was about 160 tons, of which 36½ tons had breaks applied, namely the tender, two four-wheel break vans, and one carriage. Four experiments were made, in each of which the speed of the train was first got up to 40 miles an hour; and in the first experiment the steam was simply shut off, and neither breaks nor counter-pressure were applied, but the speed was left to die out until the train came to a stand of its own accord. In the next experiment, the breaks alone were applied for stopping the train, without the counter-pressure steam; and in the third experiment the counter-pressure was used alone, without the breaks; while in the last experiment both counter-pressure and breaks were employed simultaneously.

In the first experiment, the steam being simply shut off and the engine left in forward gear, the train came to rest in a distance of 1792 yards, or 5376 feet. The velocity of 40 miles an hour being that due to a fall from a height of 53·78 feet, the work stored up in the train of 160 tons running at that speed was 53·78 × 160 = 8605 foot-tons, which divided by the distance run of 5376 feet gave 1·60 ton as the average resistance bringing the train to rest. Of this resistance, about 0·25 ton was due to the vacuum in the cylinders, which was ascertained by the indicator diagram, Fig. 12, Plate 5, taken while running at 8 or 10 miles an hour with the steam off, to amount to 7 lbs. per square inch: each 1 lb. per square inch upon the pistons being equivalent to 81 lbs. at the circumference of the driving wheels, the vacuum of 7 lbs. per square inch produced a resistance of about $\frac{1}{4}$ ton to the motion of the train. That amount of vacuum taken at 8 or 10 miles an hour he thought might fairly be considered to represent the average vacuum during the whole time the train was coming to rest from 40 miles an hour; for another diagram, Fig. 13, taken at about the very last turn of the engine wheels before stopping, showed a vacuum of as much as $3\frac{1}{2}$ lbs. throughout the stroke. The mean of the frictional resistance bringing the train to rest in this experiment, added to the decreasing resistance of the air, was therefore 1·35 ton.

In the next experiment, with the application of the breaks only, without the use of the counter-pressure steam, the train was brought to rest from the speed of 40 miles an hour in a distance of 1080 feet. Then the previous amount of 8605 foot-tons, being divided by 1080 feet, gave 7·97 tons total resistance; and deducting the resistance of 1·60 ton ascertained in the previous experiment, the remainder 6·37 tons was the resistance produced by the breaks. This amount, divided by the total weight of 36·50 tons to which the breaks were applied, gave $\frac{6·37}{36·50} = 0·17$ or about $\frac{1}{6}$th as the coefficient of break friction; and the highest coefficient that he had been able to find as ever having been obtained from similar breaks was $\frac{1}{5}$th or 0·20. In this experiment the tender wheels were skidded by the breaks, but he did not know whether the wheels further along the train were revolving or skidding.

In the third experiment, applying the counter-pressure steam alone without the train breaks, the reversing lever was thrown over into full backward gear, and the regulator left wide open; and a jet not of water but of steam from the boiler was injected into each exhaust branch. The train was then brought to rest from the speed of 40 miles an hour in 2712 feet, giving $\frac{8605}{2712} = 3·17$ tons as the total resistance; and as the vacuum produced in the cylinders in the first experiment was not formed when running with the counter-pressure steam, the deduction to be made from the total resistance of 3·17 tons in the present case was the net resistance of

1·35 ton produced by the friction of the train without the breaks and by the resistance of the air, leaving 1·82 ton as the resistance produced by the continuous application of the counter-pressure steam.

In the fourth experiment, applying the counter-pressure steam in conjunction with the breaks, the actual distance in which the train was pulled up from the speed of 40 miles an hour had not been noted, and an exact comparison could not therefore be made with the previous results. A further trial was made in approaching a station at which the train was to stop: on arriving at the distance where it was the usual practice to shut off the steam and to apply the breaks, the engine was reversed to work counter-pressure, without the steam being shut off; the breaks were not applied at all, but nevertheless the train was brought to rest at the distance of three telegraph posts before reaching the station, or about 180 yards sooner than in ordinary stopping by the breaks alone without the counter-pressure steam. On repeating this trial at another station, and reversing the engine a little later than the usual place of shutting off steam, the train was stopped at the station, the engine only overrunning by its own length the station platform.

From these results he thought it was clear that the use of counter-pressure steam was completely successful in giving sufficient retarding power for the ordinary working of trains, enabling them to be stopped at stations without the use of the breaks at all; and calculation based on the results obtained on the level showed that trains might also be worked down inclines of as much as 1 in 80 without the breaks being applied. This he considered a most important step to have been made in the working of railways; as to get rid of the bad effect of the breaks on the wheels, and the further bad effect produced on the rails by the wheels worn into polygons by skidding, was to ensure a great economy in the cost of repairs and renewals. For steep inclines, or for pulling up a train quickly to avoid collision, he considered it would not be prudent to dispense with the present train breaks, which should still be retained ready for instant application to their full extent; and the only doubt he felt in relation to the counter-pressure working was whether the train breaks, when so much less generally in use, would be applied with sufficient promptness and effect on occasions when they were called for in any emergency requiring their immediate application.

In the case of stopping the trains by the counter-pressure steam alone, without the breaks, the calculated resistance of 1·82 ton at the circumference of the driving wheels was equivalent, as previously explained, to a pressure of 50 lbs. per square inch exerted upon the pistons by the counter-pressure steam throughout the whole stroke; and the indicator diagram, Fig. 9, Plate 4, which was taken immediately after reversing the engine in this experiment, showed a mean counter-pressure of 63 lbs. throughout the stroke. Unfortunately the spring which caused the indicator barrel to revolve was broken after this diagram had been taken, and he had therefore not been able to take diagrams on the occasion of the further trials on that day. The mean counter-pressure of 63 lbs. would however diminish as the speed fell off, for the reason which he would explain; and another diagram, Fig. 10, taken on the following day at a speed of only 8 to 10 miles an hour with a rather lower boiler pressure, showed a mean counter-pressure of only 38 lbs. throughout the stroke. These two diagrams therefore were sufficient he thought to confirm the result arrived at by calculation of 50 lbs. per square inch as the average counter-pressure exerted by the steam during the whole time of bringing the train to rest from the speed of 40 miles an hour.

A remarkable feature in the counter-pressure diagram, Fig. 9, Plate 4, was the great height to which the pressure rôse in the cylinder immediately upon the opening of the communication to the boiler by the slide-valve, amounting to as much as 150 lbs. pressure per square inch, or 30 lbs. above the actual boiler pressure of 120 lbs. There were even indications in the diagram which led him to believe that, had it not been that the range of the indicator spring was limited to 150 lbs., the line of the diagram would have risen still higher. This great excess of pressure in the cylinder above the boiler pressure caused him at first to doubt the accuracy of the indicator; but on carefully testing it by actual weights it was found to be perfectly true; and also on checking it with the steam gauge on the boiler, the two were found to agree closely at the boiler pressure of 120 lbs. Moreover an indicator diagram, Fig. 11, Plate 5, taken at a low speed in ordinary working, not reversed, showed that the steam pressure in the cylinders up to the point of cut-off was as usual only about 3 lbs. below the boiler pressure; and also the counter-pressure diagram, Fig. 10, taken in the reversed working at a low speed of only 8 to 10 miles an hour, showed a maximum of only about 113 lbs. in the cylinders, the boiler pressure having fallen at the time that this diagram was taken. He was therefore satisfied that the accuracy of the diagram Fig. 9 might be relied upon as not recording a greater pressure than did actually exist in the cylinders at the time of taking the diagram. It appeared to him that the only explanation of this excess of 30 lbs. per square inch above the boiler pressure was the high velocity with which the steam was moving in the steam pipe. At a speed of train of 40 miles an hour, the time occupied by the piston in traversing the length of the cylinder was about 1-6th of a second; while the counter-pressure diagram showed that about 1-6th of this time, or only 1-36th of a second, was actually occupied by the steam, after the opening of the port by the slide-valve, in filling the portion of the cylinder that was then in communication with the boiler, which portion would be about half the capacity of the cylinder, or about 1 foot length of the stroke. The area of the steam pipe being only 1-16th that of the cylinder, the velocity of the rush of steam through the steam pipe into the cylinder must therefore be about 576 feet per second; and under these circumstances he thought it was not unreasonable to suppose that the boiler steam, notwithstanding its extremely low density compared with water, would act as a ram in a manner similar to an ordinary hydraulic ram, where a column of water in motion was suddenly checked. In the present instance, where there was a great length of steam pipe inside the boiler, extending about 16 feet from the regulator at the firebox end to the cylinders, there would be ample momentum stored up in this long column of steam moving at about 576 feet per second, to produce the effect of increased pressure in the cylinders which was shown by the indicator diagram Fig. 9 of the counter-pressure working. A confirmation of this view was afforded by the similar rise of pressure shown in the indicator diagrams accompanying the paper, in which it was seen that the counter-pressure in the cylinders at the end of the stroke rose above the boiler pressure, though the amount of the excess of pressure was not so great in those diagrams, as they had been taken he understood at a lower speed of not more than 18 miles an hour; and the regulator was probably situated close to the smokebox end of the boiler, and therefore much nearer the cylinders, in the French locomotives than in the one on which he had experimented.

Mr. W. G. Beattie said he had been present at the experiments now described on the South Western Railway, and he was satisfied that at the time of taking the indicator diagram, Fig. 9, Plate 4, in the counter-pressure working, there was really the pressure of steam in the cylinders that was shown by the diagram; as the slide-valve at that time was not closed, but very nearly full open, it was impossible for the high pressure in the cylinder to be the result of any compression arising from throttling of the steam passages, the port being freely open for the steam to be forced back into the boiler. In the trial made of pulling up the train by the counter-pressure steam in conjunction with the breaks, the retarding effect produced was not very much greater than that obtained with the breaks alone, without the counter-pressure, the train being pulled up only a few yards sooner than by the breaks alone; there was however some doubt as to the accuracy of the observations in this experiment. It appeared to him that the counter-pressure would not be of so much use, as far as the avoiding of collisions was concerned; but a very important question in railway traffic was not as to the avoiding of collisions, but as to the means of readily pulling up the trains in the regular daily working. In this respect he thought there was reason to expect that, by employing the counter-pressure and the breaks together, the trains might well be worked quicker than at present, and the traffic might be got through more expeditiously, especially on parts of the line where there was a crowded traffic. It was intended now to make further trials of the counter-pressure plan, with a view to its practical adoption.

Mr. W. Kirtley said a preliminary trial of the counter-pressure plan had been made a short time ago with a light tank engine on the Midland Railway, and they had been much surprised at the results; and in consequence a larger tank engine had now been fitted with the counter-pressure apparatus, and trials had been made with it on the Lickey incline of 1 in 37. Owing however to an oversight, the regulator had been kept closed in the reversed working of the engine, instead of being kept open throughout, as should have been the case; and the effect of the counter-pressure was therefore obtained only from the compression of the steam supplied by the jet of hot water that was discharged into the base of the exhaust-pipe. The engine was a very heavy one, intended expressly for working that incline, its weight in working order being 36½ tons; it was a six-wheel coupled engine, with 4 feet wheels, and cylinders 16½ inches diameter by 24 inches stroke. The trials were all made running down the incline, and the retardation was produced by reversing the engine into full backward gear and turning on the water jet for a short time; the cock of the water jet was opened by a screw, requiring exactly 2¾ turns to open it fully, and the area of passage when full open was 0·518 square inch. The reversing was effected by screw reversing gear; but this was too tight at first, being new, and it took two or three minutes to bring the lever over into full backward gear.

In the first trial, made with the engine only, the boiler pressure being 100 lbs. and the speed 20 miles an hour, the water jet was applied after reversing the engine by giving three or four turns to the handwheel of the water cock; and the water being kept on, the speed was thus reduced to 5 miles an hour, large quantities of water being thrown out at the chimney top, even after the jet had been turned off again. The engine could not be brought to a stand on the incline without the use of the break; but this was afterwards found to be because too much water had been turned on.

In the next trial, the boiler pressure being 140 lbs., the engine took down a load of 42·40 tons, consisting of four of the incline break wagons weighing 10·60 tons each, with the breaks all off. At the speed of 20 miles an hour the water cock was opened two turns, and was turned off again in about one minute after being turned on; the speed was thus reduced to 15 miles an hour and prevented from exceeding that rate. A good deal of water was thrown out at the chimney top, but not so much as in the previous experiment. On repeating this trial several times, the speed was reduced to 10 miles an hour, but could not be got lower.

In the third experiment, the engine took down a train, composed of engine and tender weighing 50 tons, ten loaded coal wagons weighing 100 tons, eight empty vans weighing 40 tons, and one guard's break van weighing 8 tons, making a total load of 198 tons; the breaks of the ten coal wagons were all pinned down, but the guard's break and the tender break were off. The boiler pressure was 140 lbs., and at the speed of 20 miles an hour, the water cock was opened one turn, and was kept open one minute and then closed; the speed was thereby reduced to 12 or 14 miles an hour, and prevented from exceeding that rate; and water was thrown out at the chimney top like a fine spray. This experiment was repeated several times with the same result.

The fourth experiment was made with the engine only, the boiler pressure being 140 lbs. At the speed of 20 miles an hour the water cock was opened half a turn, and closed again in half a minute. This brought the engine to a dead stand on the incline in 100 yards. The speed was then allowed to reach 30 miles an hour, and the water cock being opened half a turn and shut again in about 8 seconds, the engine was brought to a stand in about 150 yards. No water issued from the chimney top, and only a little steam was visible there; there was no jarring or noise in the stopping of the engine. After coming to a stand, the engine wheels made one revolution backwards, up the incline, corresponding to the position of the reversing motion in full backward gear.

In the next experiment, the engine took down five incline break wagons, making 53 tons total load, the breaks being all off. At the speed of 20 miles an hour the water cock was opened half a turn and shut again in 8 seconds, which reduced the speed in 200 yards to only 2 miles an hour. The speed was then allowed to reach 25 miles an hour, and the cock opened and closed again as before; and when the speed was thus reduced to 10 miles an hour, the cock was opened a second time; this however did not diminish the speed, and rather seemed to injure the effect of the first opening. On again attaining the speed of 25 miles an hour, the cock was opened half a turn and closed in 6 or 8 seconds, which brought the train to a stand in about 200 yards. No water was discharged at the chimney top, but only a slight puff of steam.

The sixth experiment was made with a train of six loaded coal wagons weighing 58·61 tons, and two incline break wagons weighing 21·20 tons, making a total load of 79·81 tons. The boiler pressure was 150 lbs., and at 16 miles an hour the water cock was opened nearly half a turn and kept open for 5 seconds; the speed was thereby reduced in $\frac{3}{4}$ mile to about 3 miles an hour. Again at 20 miles an hour the water cock was opened a quarter turn for 6 or 8 seconds, which reduced the speed in about $\frac{3}{4}$ mile to a mere crawl. No water issued from the chimney top.

In the last experiment the engine took the same train down the incline with the addition of two more of the incline break wagons, making the total load 101 tons. At a speed of 18 miles an hour the water cock was opened half a turn for 5 seconds, by which the speed was reduced to 10 miles an hour; but the train could not be kept down to that speed, and ran through the station at the bottom of the incline at the rate of 15 miles an hour with the reversing lever still in backward gear. This last trip burnt the packings, and one piston got rather hot.

Mr. E. A. Cowper supposed that as the regulator had been kept shut during the reversed working, in the experiments just described on the Lickey incline, the slide of the regulator must have got lifted off its face by the pressure of the steam underneath it, which was being pumped back into the boiler from the cylinders when the water jet was turned on; and he enquired what rise of pressure had been observed to take place in the boiler, in consequence of running reversed with the water jet on. He asked also whether the engine wheels had been skidded on any occasion by the resistance of the steam that was compressed in the cylinders.

Mr. C. VAUGHAN replied that the rise of pressure in the boiler while running reversed during the experiments had been found to be about 3 lbs.; and the regulator was made with an ordinary gridiron opening and slide, the slide being free to be lifted off its face by any pressure in the steam pipe above the boiler pressure. The engine wheels were not in the least skidded by the resisting effect of the steam compressed in the cylinders, but continued revolving in the forward direction, the same as in ordinary running not reversed.

Mr. W. M. MOORSOM said that experiments with the counter-pressure working had recently been tried on the London and North Western Railway, on the line from Buxton to Stockport, where there was an incline of 1 in 60 average gradient for 6 miles distance from Doveholes down to Whaley Bridge station, on which the trials had been made. These experiments were conducted under rather unfavourable circumstances, as they had to be made at night. The engine employed was a six-wheel coupled, with wheels 5 feet diameter, and cylinders 17 inches diameter by 24 inches stroke; its weight in running order was 27½ tons, and the tender weighed 16 or 17 tons; and the weight of the train taken down the incline by the engine in the experiments, consisting of several mineral wagons and one break van, was 250 tons. The engine started with 100 lbs. boiler pressure, and with one injector at work feeding the boiler; and on passing over the brow of the incline, where the speed was about 10 miles an hour, the steam was shut off, and the water injection cock turned on, admitting the jet of hot water from the boiler into the exhaust-port; and as soon as there was a discharge of water from the funnel, which fell like rain on the foot-plate, the engine was reversed into full backward gear; after which the regulator was immediately opened again to the full extent, for applying the counter-pressure steam in the cylinders. The speed of the train however increased, and continued increasing until it was about 16 or 17 miles an hour, which was considered too fast for descending the incline; and the tender break was therefore put on slightly, which reduced the speed to about 10 or 12 miles an hour. In this way the train ran down to Whaley Bridge, but in order to stop at the station the guard's break and the tender break had both to be applied, which brought the train to a stand in a short distance. The experiment was repeated in the same manner on the following night, and on both nights it was found that, when the water injection cock was only so much opened as to produce a cloud of steam and a fine spray from the funnel, the injector feeding the boiler would not continue working, but ceased work after running about a mile down the incline, and could not be made to start again so long as the counter-pressure jet was kept the same; but by turning on such an amount of water into the exhaust-pipe that the spray from the funnel was much thicker and fell in large drops, they had managed to make the injector work again. When the water jet was kept on sufficiently to maintain the injector at work all the time of going down the incline, the boiler pressure fell from 100 lbs. at the top of the incline to 80 lbs. at the bottom; this was the case in the second night's experiment, but on the first night the injector was only at work a short distance down the incline. The engine had been at work on the same incline during the week previous to these experiments, and the driver had reported that, when very little water was turned on at the jet in the exhaust-pipe, the boiler pressure rose almost immediately to the point of blowing off, 120 lbs., and continued blowing off all the way down the incline, but the injector would not work. Although the engine was fitted with screw reversing gear, so that it could readily be reversed without shutting off steam, the object of closing the regulator before opening the injection cock and reversing had been to reduce the discharge from the funnel to that caused by the water injection only, so that the proper opening of the injection cock might be readily determined. The engine wheels had never been skidded by the counter-pressure steam, except on one occasion while going through a tunnel, where the wheels slipped on the rails.

The PRESIDENT said that the engine fitted with the counter-pressure apparatus on the London and North Western Railway had been put into the hands of a careful driver, and the report he had received from him was that the injectors would not work, while running with the counter-pressure steam. He found however that the reversing of the engine had at first been done before turning on the water jet in the exhaust-pipe, and the engine must consequently have been pumping air into the boiler, which would account for the injectors ceasing to work. Instructions had therefore been given for turning on the water jet first, before reversing; but notwithstanding this it appeared there was still some difficulty in keeping the injectors at work, unless the water was supplied considerably in excess in the counter-pressure jet. He could only suppose that there must still be some portion of air taken into the cylinders in the reversed working; and until this difficulty was got over by further practice in the counter-pressure working, it might be advisable to employ a separate steam jet in addition to the water jet, in order completely to prevent any access of air into the interior of the blast-pipe and thence into the boiler.

The working out of the counter-pressure plan in practice could hardly be expected not to be attended with some difficulty at first; and one source of trouble that occurred to him as likely to be met with was from the very dirty nature of the water in the boilers of locomotive engines. However pure the water supplied to the boiler might be, the concentration which it underwent in the boiler was so rapid, that any water not absolutely pure to begin with became soon charged to saturation with calcareous salts, the presence of which he considered would be liable to produce injury to the rubbing surfaces of the cylinders and pistons. But whether the extent of injury thus occasioned would be material in comparison with the loss at present sustained in the wear and tear of rails and tyres, was a matter that could be determined only by experience. From what he had seen and heard of the counter-pressure steam break, he was disposed to place a higher value upon it than to limit its capabilities to the working of inclines of only 1 in 80; and he believed it would be found of material assistance in taking trains down very heavy gradients. On the Tredegar and Abergavenny line in South Wales there was a descent of 1000 feet within a distance of only 8½ miles, giving a mean gradient of 1 in 45, and the difficulty of taking the trains down that part of the line was found to be practically even greater than getting them up; and in this case he was looking to the application of the counter-pressure working for surmounting to a great extent the difficulty at present experienced. In applying the counter-pressure steam for ordinary stoppages at stations, the quantity of injection water required to be turned on would of course diminish as the speed became reduced; and he was prepared therefore to anticipate some difficulty in this application of the plan, as the regulation of the jet would probably require a nicety of adjustment that was scarcely to be expected from the ordinary class of enginedrivers. Another application mentioned in the paper of the counter-pressure working was for shunting at stations, the regulator being kept open the whole time, and the shunting being effected entirely by the reversing lever; and in order to carry this plan out, it was necessary not only that the screw reversing gear should be employed, but also that the engine should be fitted with good balanced slide-valves; otherwise it was certain the men would still continue to shut off the steam before reversing, in order to render the reversing easier. In the experiments on the Buxton line it had been mentioned that the steam had been shut off in order to reverse the engine, and it was clear the regulator had been used largely in the trials; and the men would not be got to desist from employing it extensively until the reversing was rendered as easy with the steam full on as with it shut off, which it appeared to him could not be readily accomplished.

In regard to the excess of pressure shown above the boiler pressure in the counter-pressure diagram that was exhibited from the experiments on the South Western Railway, the explanation which had been offered, viewing the column of steam in the steam pipe from the regulator to the cylinders as performing the part of a ram, appeared to him to be corroborated by the circumstance of the engine being an outside-cylinder one with separate steam-chests and forked steam-pipe, increasing considerably the distance from the regulator to either cylinder. In an inside-cylinder engine, where the total length of the steam-pipe would be less, and where also the action of one piston might perhaps interfere somewhat with that of the other in forcing the steam back into the boiler, in consequence of the two cylinders having only a single steam-chest common to them both, it was probable the excess of counter-pressure might not be quite so great as in the diagram shown. Another reason that would account for the high pressure observed in the cylinder was the greater density of the counter-pressure vapour which had to be forced back by the piston into the boiler; it was not boiler steam alone, but a wet vapour largely charged with water from the water jet, which would therefore move more sluggishly through the passages to the boiler. That the momentum of the boiler steam rushing into the cavity of the cylinder would be great enough to produce a considerable rise of pressure in the cylinder above the boiler pressure appeared to him a reasonable supposition; and he remembered hearing a somewhat analogous circumstance, that in gunnery it was a well-known fact that when a charge was not rammed home the strain upon the gun in firing was more severe, producing a greater expansion at the breech.

Mr. J. Robinson mentioned that experiments had been made on the South Staffordshire Railway some years ago by Mr. Holt with a similar plan of counter-pressure working; and he enquired what had been the results of that trial, and why it had not been followed up.

Mr. F. Holt said the object he had had in view had been to make use of the engine as a break power; and knowing the difficulty of doing so by running reversed, in consequence of the want of lubrication for the rubbing surfaces of the cylinders and pistons in the reversed working, it had struck him that the application of water might be successful for the purpose. He had made a trial of the plan about fourteen years ago with a new goods engine, by inserting a $\frac{3}{8}$ inch gas cock in the mud plug at the bottom of the smokebox tube-plate, and carrying a small pipe from this cock up to the mouth of the blast-pipe and then down inside the blast-pipe to the bottom, so as to discharge a jet of hot water from the boiler into the exhaust-port of each cylinder; the quantity of water in the jet was regulated as required by a rod worked from the foot-plate. With this apparatus the engine was worked down inclines with the valve-motion reversed into full backward gear and the water-jet turned on, and the regulator kept full open all the time, thus giving the effect of the counter-pressure steam in retarding the motion of the train. The engine worked down the gradients of about 1 in 120 between Cannock and Wichnor Junction, and also down the incline of about 1 in 75 from Dudley Port to Dudley. As however locomotive engines at that time had only the ordinary reversing lever held by a detent, instead of the screw reversing gear subsequently introduced, the reversed running was attended with much risk; and after about a week or ten days' successful working, the unfortunate accident occurred of the lever getting liberated and flying over into forward gear, by which the lever was broken and some damage done to the engine. In consequence of this mishap, he had been prevented from proceeding with any further trial of the plan, notwithstanding that the result had been so far satisfactory in all other respects; he had been confident the principle of counter-pressure working was one of great value and would be attended with great success in practice, and that it would sometime come into use; and he was very glad therefore to find this confirmed by the extensive application that was now being made of the plan, and considered great credit was due to M. Le Chatelier for the manner in which he had taken the matter up and carried it out.

Mr. Siemens remarked that he was much gratified to find the interest which had been created in the subject of counter-pressure steam, and to hear what had been done since the reading of the paper at the last meeting towards carrying out the practical application of the plan in this country. He had no doubt its important advantages would become more and more appreciated with further experience, and the difficulties which had now been mentioned as having been met with in these first trials were only of an introductory kind. With regard to the difficulty experienced from the injector ceasing to work when the counter-pressure steam was applied, he agreed in thinking it might be safer at first to blow a little steam into the exhaust-pipe, in addition to the water jet, so as to prevent the possibility of any air being drawn into the cylinders. That was the plan adopted in France till very lately; but in the French practice the jet of water alone seemed now to have come to be generally preferred, which might be due to the greater experience the men had had in working the apparatus, and it would probably be found after longer experience in this country that the steam jet could be dispensed with without inconvenience. It appeared to him a curious circumstance that the previous attempt at counter-pressure working which had been mentioned had not been followed up at the time, and that the first mishap that was met with had been permitted to cause the abandonment of a plan which had now been carried out so extensively and with so many advantages. In reference to the high pressure of steam shown by the counter-pressure diagram to exist in the cylinders in excess of the boiler pressure, he thought the explanation which had been offered, on the ground of the very high velocity of the steam entering the cylinders, was the only one possible; but whether this was theoretically sufficient to account for so great an excess of pressure as was shown in the diagram would have to be determined by an elaborate calculation of the actual velocity and inertia of the steam in rushing through the length of the steam pipe into the cylinder.

Mr. E. A. **Cowper** observed that in the indicator diagram exhibited from the counter-pressure working, Fig. 9, Plate 4, the compression curve appeared unusually flat between the closing of the exhaust port and the opening of the steam port to the boiler, the pressure apparently continuing nearly the same throughout that portion of the stroke, notwithstanding the compression to which the steam was subjected by the reversed motion of the piston; and he enquired whether it was likely this circumstance, as well as the great excess of pressure at the end of the stroke, could have been occasioned by the indicator piston sticking a little at the top and bottom of its stroke, in consequence of an accumulation of water in the indicator cylinder owing to the very wet nature of the steam.

Mr. F. J. **Bramwell** replied that he had not found any signs of the indicator piston sticking at any part of its stroke in taking the diagrams; the same character was seen also in the other counter-pressure diagram, Fig. 10, taken when the engine was running slowly, in which a nearly horizontal line was shown at the part where the compression curve would be expected. On examining a full-sized model of the link motion of the engine he had found that in the reversed working the exhaust port was open to the atmosphere for 13 per cent. of the stroke, and the steam port was opened to the boiler at 37 per cent. of the stroke, when in full backward gear; the contents of 87 per cent. of the stroke were therefore compressed into 63 per cent. before the communication to the boiler was opened, and he should have expected a corresponding rise of pressure to be shown in the indicator diagrams at that part of the stroke.

Mr. SIEMENS observed that in compressing pure steam, the curve of compression would rise more rapidly than the theoretical curve which merely represented the increase of pressure as inversely proportionate to the volume, because the steam would become superheated in the compression and the heat then developed would cause its pressure to be further raised. But the case was different in dealing with a fog or vapour containing a quantity of finely divided water not in the state of steam, such as was enclosed in the cylinder on the shutting of the exhaust-port in the counter-pressure working; nearly 9-10ths by weight of the vapour was at that time in the form of water, which would act as so much condensing water in the compression, reabsorbing the heat produced by the compression, and thereby keeping the pressure down to very nearly the same point for a certain distance of the stroke before the boiler steam was admitted. This circumstance he had no doubt was the cause of the apparent irregularity shown in the compression part of the stroke in the indicator diagrams exhibited.

Mr. W. M. MOORSOM enquired whether any observations had been made in France as to the working of the injectors during the time that the water jet was turned on in the counter-pressure running.

Mr. SIEMENS replied that the early experience in France had been the same upon that point as in the experiments now made in this country, the injectors being found at first to cease working when running reversed; but this difficulty had been entirely got over by taking care to turn on the water jet in the exhaust-pipe before reversing the engine, and that was a precaution which was specially recommended by M. Le Chatelier, for preventing any chance of air getting drawn down the exhaust-pipe into the cylinders.

Mr. R. Brown mentioned that at a former meeting of the Institution a simple plan had been described by Mr. Allan, having also the object in view of employing the engine as a break for retarding the train, (see Proceedings Inst. M. E. 1859 page 230). In that case a throttle-valve placed in the exhaust-pipe was closed for preventing the escape of the steam from the cylinders, thereby producing a heavy back pressure to resist the movement of the pistons. By that means a train of 200 tons had been taken down an incline of 1 in 80, and the speed of 30 miles an hour at starting reduced to 15 miles an hour down the whole incline; and the particulars had been given of a number of trials, showing the very satisfactory working of the plan.

The President said he remembered the description being given of the plan referred to, which however was altogether distinct from the present counter-pressure working, as the engine was not necessarily reversed in that case; nor was any suggestion made of introducing the jet of steam or water into the exhaust-pipe for lubricating the rubbing surfaces while running as described, which

A paper was then read "On the Further Economy of Fuel in Blast Furnaces, derivable from the High Temperature of Blast obtained with Cowper's improved Regenerative Stoves at Ormesby, and from Increased Capacity of Furnace, &c.," by Mr. Charles Cochrane, of Dudley; and the discussion was adjourned to the next meeting. (See Proceedings April 1870).

The Meeting then terminated; and in the evening a number of the members dined together in celebration of the Twenty-third Anniversary of the Institution.

PROCEEDINGS.

28 April, 1870.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 28th April, 1870; John Ramsbottom, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been duly opened, and the following New Members had been found to be elected:—

MEMBERS.

Hubert Bewlay,	Birmingham.
James Brunlees,	London.
James Henry Greaves,	Swansea.
James Eglinton Anderson Gwynne,	London.
John Gwynne,	London.
Joseph Edward Hannah,	Darlington.
Charles Hawksley,	London.
John Higson,	Manchester.
Samuel Osborn,	Sheffield.
Edward James Reed, C.B.,	London.
Thomas Stubbs,	Crewe.

GRADUATE.

Thomas Henry Pearson,	Warrington.

The adjourned discussion was then resumed upon the paper read at the previous meeting of the Institution in January, "On the Further Economy of Fuel in Blast Furnaces, derivable from the High Temperature of Blast obtained with Cowper's improved Regenerative Stoves at Ormesby, and from Increased Capacity of Furnace, &c.," by Mr. Charles Cochrane, of Dudley.

ON THE FURTHER ECONOMY OF FUEL IN BLAST FURNACES, DERIVABLE FROM THE HIGH TEMPERATURE OF BLAST OBTAINED WITH COWPER'S IMPROVED REGENERATIVE STOVES AT ORMESBY, AND FROM INCREASED CAPACITY OF FURNACE, &c.

By Mr. CHARLES COCHRANE, of Dudley.

(*Read at the Meeting on 27th January*, 1870.)

The original construction of the Regenerative Hot-Blast Stoves working at the Ormesby Iron Works, Middlesbrough, at a temperature of 1300° Fahr., was described in a paper by Mr. Cowper at a former meeting of this Institution about ten years ago (see Proceedings Inst. M. E. 1860 page 54); but in some points of detail the stoves have been subsequently modified to a considerable extent, from the results of the long experience with them.

The stoves as now used are shown in Figs. 1 to 4, Plates 6 to 8; and each consists essentially of an air-tight skin or casing of wrought iron, $\frac{3}{8}$ to $\frac{1}{2}$ inch thick, lined with firebrick 18 inches thick. In the centre of the stove is a shaft 5 feet diameter and 14 inches thick, at the bottom of which is an argand burner A, Figs. 1 and 2; the gas is admitted through the valve B and tube C, Fig. 4, to the centre of the shaft, where it meets with the atmospheric air required for its combustion, the air being delivered through the valve D and tube E to the annular space F. Ignition commences the moment the gas meets the air, the shaft being previously heated to a sufficiently high temperature; and the ignition is continued up the central shaft, until the partially burned gas and air impinge on the centre of the dome G G, by which they are deflected and intermixed, so as to effect as perfect a combustion as possible before reaching the upper surface of the regenerator H H. This is a point of great importance for securing the best results in the employment of waste gas from blast furnaces; for in order to get the greatest amount of duty out of the gas, it is essential that its combustion in small passages should be avoided. This condition is so indispensable, both for stoves and boilers heated by waste gas, that special combustion chambers are now always provided for the purpose; or the boilers are so lengthened and the stoves so arranged as to supply the requisite total space for securing the greatest development of heat of which the gas is capable.

The heated products of combustion impinging upon the top of the regenerator impart a certain amount of heat to it, until complete saturation has taken place; and each of the successive lower courses of brickwork in the regenerator takes up a portion of the heat that is left in the gas, and becomes heated up towards the temperature of the top course, according to the length of time of exposure to the gas. The spent gas is finally collected beneath the regenerator in the passages I I, Fig. 1, and escapes by the chimney valve K, Fig. 4, and through the flue L into the chimney at the low temperature of only about 300°, having been cooled down in the process from an original temperature of probably 2300°. This result is obtained with a height of regenerator of about 26 feet from the lowest layer of open brickwork to the upper surface of the regenerator.

The heating of the regenerator is effected by this means, and the hot and cold air-valves M and N, Figs. 1 and 4, are closed during the time required for this purpose. In order to impart to the blast the heat thus stored up in the regenerator, the gas valve B, the air valve D, and the chimney valve K, are first closed; the cold-blast valve N is next opened, and then the hot-blast valve M; the process of heating the blast then commences at once, and the stove is said to be "on." The cold air admitted at N enters the coolest portion of the stove, namely the passages I I, from which it ascends through the mass of the regenerator till it reaches the surface of highest temperature H H; and it then descends in its heated condition through the central shaft, and passes along the flue O within the stove, and finally makes its exit through the valve M into the general hot-blast main P, which is 5 feet diameter outside and lined with 15 inches thickness of brickwork.

The reverse process takes the other stove of the pair "off," and it is then heated up in a similar manner by the gas, in preparation for heating the blast. Two stoves are here referred to, and two at least are requisite, alternating with each other in the process of heating the blast; and in that case if a stove be 4 hours in delivering up its heat, only 4 hours can be allowed for restoring the heat abstracted from the regenerator. In practice three stoves are found preferable to two, as producing the greatest uniformity and the maximum temperature in the blast, owing to the circumstance that each of the three stoves can be heated up for a period of 4 hours, whilst the blast is only allowed to pass through the regenerator for 2 hours, and thus a greater command of temperature is obtained.

The size of the chimney is a point of importance; one of 100 feet height and 7 feet diameter octagonal at the top, or 41 square feet area of passage, has been found rather too small for a pair of stoves heating 8000 to 9000 cubic feet of blast per minute; and another chimney is consequently being erected to take its place, of 120 feet height and 8 feet diameter octagonal, increasing the area to 53 square feet. Wherever practicable, the writer recommends the delivery of the spent gas from the stoves into a single large chimney, arranged to carry off also the products of combustion from the boilers.

The purification of the blast-furnace gas from the dust that is carried along in it from the furnace has been found necessary in applying it to the regenerative stoves, as every course of brickwork in the regenerator interposes an obstruction to the passage of the dust conveyed in the gas; and the apparatus shown in Figs. 7 to 10, Plates 10 and 11, has been adopted at the Ormesby Iron Works for removing the dust as far as practicable, previous to the combustion of the gas in the stoves. The purifier consists simply of a series of horizontal cast-iron trays, arranged in a number of tiers above one another, and exposing to the gas a total depositing surface of about 23,000 square feet area. The trays are perforated with a number of long narrow slots, through which the gas and dust descend successively from each tray to the tray below; and the depositing surface in each tray is immediately under the orifices through which the gas and dust pass in the tray above.

The gas as taken off from the blast furnace is admitted to the purifier through the main flue A, Figs. 7 and 8, and meets at B with a stop built into the flue, by which it is made to ascend the vertical flues C C; at the top of these the gas spreads out on opposite sides into the twelve compartments D D, Figs. 9 and 10, which are each about 8 feet long by 5 feet wide. The gas then descends through the series of 32 trays provided in each compartment, depositing on each tray in succession a portion of the dust with which it is charged. The subdivided currents of gas unite again in the lower portions of the compartments, which communicate with one another through the openings K K; and the gas then escapes through the outlets E E, Figs. 7 and 8, to the back of the stop B in the main flue. A similar process is effected in the second half of the purifier; and the final exit of the purified gas takes place through the openings F F into the general main G. Explosion valves H H are provided where requisite; and each compartment is closed by three doors I I, which give access for cleansing the trays, and are made gas-tight by loam joints.

In purifying the gas for the stoves for one furnace, a total area of gas passage of 68 square feet through the purifier has been found efficient for the purpose of depositing the dust; and a larger area of 107 square feet that was tried gave no additional advantage in this respect.

In the details of construction of the regenerative stoves, several material improvements have been effected upon the original construction. One of these consists in placing the bricks in the regenerators 3 inches apart instead of only 1 inch; and the bricks have been reduced in thickness horizontally from 2½ to 1 inch. The intermediate bricks $1\frac{3}{4}$ inch square, called "soap" bricks, which were originally used to separate the courses of ordinary firebrick of $4\frac{1}{2} \times 2\frac{1}{2}$ inches, have been entirely dispensed with; and the small openings in the arches originally supporting the regenerator have been enlarged to the utmost possible, by the substitution of cast-iron girders to support the regenerator bricks above. The object of these alterations has been to enlarge the gas passages, for the purpose of ensuring perfect combustion, in case the combustion may not have been thoroughly completed in the space of the dome above; and also to defer as long as practicable the time of the passages becoming so choked as to affect the working of the stoves. The combustion chamber has also been enlarged, in order that the combustion may be completed if possible before the heated gas enters the regenerator, as it is found that the maximum heat which the gas is capable of developing can be obtained only in this manner.

The construction of the hot-blast valve in the original stoves was found defective, as it exposed a large cooling surface to the current of blast on issuing from the stove. This valve has now after several failures been successfully replaced by the water valve shown in Figs. 5 and 6, Plate 9, which is an ordinary sluice valve having a current of water constantly flowing through it to keep it cool; and when opened it is drawn up into a recess, clear of the current of blast, so as not to be exposed to the direct action of the hot current. The valve seat is also kept cool by water, and is lined with brickwork to diminish as far as possible its cooling effect on the blast.

In increasing the height of the stoves to the maximum that is found advantageous, special provision has to be made for allowing the vertical expansion of the brickwork to take place without injury to the structure. The omission to provide for this expansion, in a former stove of about 25 feet height up to the springing of the wrought-iron dome, occasioned a fracture of $\frac{3}{4}$ inch width at one point of the junction of the dome with the cylindrical casing, the crack extending about a quarter round the circumference. The occurrence of such an accident has since been prevented by the introduction of a distance piece $\frac{3}{4}$ inch thick, as shown at S, Fig. 3, which is inserted all round in the joint of the dome and the cylindrical casing, after the brick dome has been constructed. The wrought-iron dome is made to form the upper backing for building the brick dome, and when this is completed the wrought-iron dome is raised $\frac{3}{4}$ inch and the thickness piece S inserted all round, thus leaving a corresponding clear space throughout between the brick dome and the wrought-iron dome. In a stove 35 feet high to the springing of the dome, this plan has effectually prevented any evil effects arising from expansion. In the construction of the stoves it is also important that the parts where the work is difficult of access, such as the bottom plates, should have the joints of the wrought-iron casing doubly caulked, as the effects of leakage of the highly heated blast are very destructive.

Seven of these stoves are now in operation at the Ormesby Iron Works, ranging in size from 3240 to 9550 cubic feet capacity of regenerator, the solid contents of the regenerators amounting to 1080 and 3040 cubic feet respectively. The height of the regenerators ranges from $12\frac{1}{2}$ to 26 feet; and each successive increase that has been made in their height and mass has resulted in increased advantage, up to the height of 26 feet, which is considered to be the limit of size that is desirable.

In the smallest size of the stoves it is found that a great waste of heat takes place at the chimney flue since the increase to 3 inches was made in the spaces between the bricks of the regenerator, the temperature of the escaping gas being from 580° to about 900°. But with the original 1 inch spaces in the same stoves the temperature of the escaping gas was too low to produce a sufficient draught in the chimney, and the draught had to be assisted by a fire. In the intermediate size of the stoves having a regenerator of 4960 cubic feet capacity, the temperature of the escaping gas is reduced, and ranges from 365° to 645°; and in the largest size of stoves this temperature is only from 244° to 334°, and the heat is so thoroughly absorbed that there appears no room for further improvement in that direction with this class of stove. From the accompanying diagram, Fig. 13, Plate 12, representing the relative draught of a chimney for different temperatures, it will be seen that the low temperature of the escaping gas, 244° to 334°, is rather below that at which the maximum work is obtained in a chimney, namely about 400°; but the corresponding economy of heat obtained in the stove may be considered to compensate for the slight loss of draught.

One great advantage that has now become fully established in the use of these regenerative stoves is the great economy of heat as compared with cast-iron stoves, in which the temperature of the escaping gas is necessarily at least as high as that of the cast-iron pipes in course of being heated. In cast-iron stoves therefore, producing as they now do a temperature of 1000° to 1100° in the blast, the temperature of the escaping gas cannot be less than 1300° to 1400°; but in the regenerative stoves about 4-5ths of this waste heat is saved.

Another great advantage is the extra temperature of blast that the regenerative stoves are capable of producing without risk of the destruction of the apparatus. The temperature of blast of 1880° has been obtained in the large stoves heated by gas, and in experimental stoves heated by coals 2000° was actually reached; and if it were advisable to adopt this temperature for the blast, there is no doubt that the brickwork of the stoves in their present form, having the hotter bricks uppermost, would stand the heat without injury. Another advantage of great practical value is the prevention in these stoves of all leakage of blast, to which in the writer's opinion every form of cast-iron stove is more or less liable; the pressure of blast at the furnace is consequently maïntained almost perfectly up to the full pressure at the blowing engine, the loss of pressure in the stoves and blast main being nearly inappreciable by the ordinary mercurial gauge.

A further advantage is the large store of heat contained in the regenerative stoves, and the small loss of heat that occurs from radiation even during several days' standing; which renders it unnecessary to burn coal as in cast-iron stoves, for maintaining the heat of the stoves during the time of standing. Also in the event of irregularities in the materials introduced into the blast furnace, the control that is possessed over the temperature of the blast in the regenerative stoves, and not possessed in cast-iron stoves which are generally worked at their maximum temperature, affords the power of preventing or largely mitigating the usual effects of such irregularities in producing white iron. In illustration of this the writer may mention the case of two furnaces, similarly circumstanced in all respects except as to the hot-blast stoves, both of which during July last had to contend with the same difficulty of inferior coke; but in the one furnace, working with cast-iron stoves, the production of white iron was 621 tons out of a total of 1724 tons, or 36 per cent.; whilst in the other furnace, with the regenerative stoves and the blast rendered temporarily hotter than usual by reducing the quantity of blast passed through the stoves, the production of white iron was only 204 tons out of 1841 tons total, or 11 per cent.

In considering on the other hand the disadvantages attending the regenerative stoves, the first point is their greater cost of construction. The total cost of the pair of stoves of the size shown in the drawings has been £3987, and the cost of the purifiers £1939, making the total cost £5926. These stoves are capable of maintaining a temperature of 1400° to 1500° in a volume of air of 8000 to 9000 cubic feet per minute. Subsequent improvements in the construction would probably reduce the above total cost to £5700, and the cost of cast-iron stoves would not be less than £4000 for heating the same quantity of blast to the ordinary lower temperature of 1000° or 1100°; making an excess of cost of about £1700 in the regenerative stoves.

Another disadvantage attending the regenerative stoves is that, notwithstanding the large depositing surface exposed in the purifiers of not less than 23,000 square feet per furnace, the gas consumed in the stoves still contains sufficient dust to effect gradually the choking up of the regenerators, which do not continue at work for a longer period than eighteen months without cleaning out. The cost of removing and replacing the regenerator bricks, which is required to be done in cleaning out the stoves, amounts to £90 per stove for the size of stove shown in the drawings; and the purifiers and flues also require cleaning out every three months at a cost of £8 per furnace. In the case of the cast-iron stoves the cost of cleaning amounts to £12 per furnace every three months.

The annual cost of the regenerative stoves is therefore as follows for one blast furnace:—

	£
Interest of cost at 5 per cent. on £5700	285
Redemption of same at 7½ per cent.	427
Cleansing of stoves and purifiers, excess over cast-iron stoves	104
Interest and redemption at 12½ per cent. on half of one reserve stove per furnace, costing say £2000	125
Renewal of bricks	36
Royalty, spread over eight years	43
Total annual cost of Regenerative Stoves per furnace	£1020

In the above calculation for renewal of bricks the amount is found to range from £16 to £27 per stove for eighteen months, and the larger amount has been taken for two stoves for one year. The cost of cleansing the stoves is £120 per year, less £16 difference in annual cost of cleansing the purifiers and the cast-iron stoves, leaving £104. The time occupied in cleansing the regenerative stoves is about eight or ten days.

The corresponding annual cost of cast-iron stoves is as follows for each blast furnace, assuming a cost of £4000 as sufficient in the case of a furnace making 450 to 500 tons of iron per week, which is the size taken as the basis of the previous calculation; but this is probably under-estimated, as that cost has been found in practice to suffice only for a make of 425 tons per week.

	£
Interest of cost at 5 per cent. on £4000	200
Redemption of same at 7½ per cent.	300
Interest and redemption at 12½ per cent. on two reserve stoves per furnace, costing £500 each	125
Renewal of stoves, once in ten years	400
Total annual cost of Cast-Iron Stoves per furnace	£1025

The result shows no advantage in either plan as to annual cost, when only the expense of interest, redemption, and renewal is considered. When however the saving of coke that is effected in the blast furnace by the hotter blast obtained with the regenerative stoves is taken into consideration, it will be seen that there is a large advantage attending their use. Cast-iron stoves, it is generally admitted, are not able to maintain a blast hotter than 1000° or 1100°; the temperature of 1000° is their general limit, but in a few instances 1100° has been obtained where the stoves are very close to the furnace. In the above comparisons it has been assumed that the given outlay in cast-iron stoves can produce the same results in quantity of iron made per week as the larger outlay in the regenerative stoves; this assumption has been made in order to avoid involving any question of difference in general charges or wages per ton of iron made, as such modifications can be better introduced in applying the calculation to any particular case.

An objection to the regenerative stoves has been suggested as likely to arise from the fluctuations in the temperature of the blast between the times of putting a stove "on" and taking it "off"; but it is found in practice that there is not any objection from this cause. In the smaller stoves a fluctuation of as much as 200° to 250° occurs in the space of 50 minutes that each is "on," without any prejudicial effect being perceived in the blast furnace, or any interference with the uniformity of quality in the iron made. This fluctuation in temperature is reduced as the size of the regenerators is increased, as shown by the following examples of actual working:—

Capacity of regenerator, cubic feet . . .	3240	4960	9550
Total fluctuation in temperature of blast, degrees	178°	225°	140°
Period of total fluctuation, minutes . . .	50	110	116
Rate of fluctuation in degrees per minute . .	3½°	2°	1⅕°

The lower the rate of fluctuation, the longer are the periods during which the stoves can be worked before changing is necessary. In practice a period of two hours is found convenient for this purpose in the large stoves; but a change every hour is essential with the small stoves when passing the large quantity of 8000 cubic feet of blast per minute. In the distribution of the total fluctuation in temperature of blast over the two hour period of working, it is a curious circumstance that sometimes the first hour shows scarcely any diminution in the temperature: this happens when the stove taken "off" has run a little beyond the period of two hours before changing, and the blast main between the stoves and the furnace has consequently become cooled down, and absorbs more than usual of the heat from the highly heated blast of the fresh stove when it is newly turned "on." Usually however the rate of fluctuation is but little greater in the second hour than in the first; and a temperature of 1500° at the commencement is found to be reduced to about 1440° in the first hour, and to 1350° in the second, being a fall of 60° and 90° respectively. The loss of temperature in the blast from radiation in the main is found to amount to 20° per 100 feet superficial of main, or a total of 109° in the whole length of the main shown in the drawings, which is 5 feet diameter and lined with 15 inches thickness of firebrick. The temperatures of blast named above have been measured at the furnace tuyere with Siemens' pyrometer, with the standard weight of 136½ grammes for the copper ball, which is heated in the blast and then cooled down in a pint of water; each degree of rise in temperature of the water is then taken to measure 50° in the copper ball. The other temperatures named have been measured with Gauntlett's pyrometer.

The subject of the probable saving of coke in the blast furnace due to increased temperature of blast has been carefully examined by the writer for some time past; and though the question is beset with considerable difficulty, he has succeeded in constructing two curves, one practical and the other theoretical, which he believes represent the true result very nearly. These are shown in the diagram Fig. 11, Plate 12, in which the horizontal dimensions represent temperatures of blast ranging from 800° up to 2000°, and the vertical dimensions represent cwts. of coke consumed in the blast furnace per ton of iron made, the size of furnace taken being 20,600 cubic feet capacity. The full line as far as 1422° temperature gives the results of actual experience, extending over a period of twelve months and carefully checked, the average temperatures of blast extending from 863° to 1422°, which is the highest average temperature of blast yet obtained in ordinary work over several months successively, occasional daily averages of 1600° and upwards having been obtained. The dotted curve gives the theoretical line after 1200° temperature of blast, and is based upon the following calculation. From 1100° to 1200° a saving of 1·12 cwts. of coke per ton of iron is effected, as shown by the full line: the consumption in the former case being 22·62 cwts. as compared with 21·50 cwts. per ton of iron in the latter case. Now in effecting, by the employment of a still hotter blast, a further saving in coke of the same amount as is accomplished between 1100° and 1200°, so as to reduce the consumption from 21·50 cwts. to 20·38 cwts. per ton of iron, the quantity of the hotter blast entering the furnace per ton of iron made will be reduced in the same ratio of 21·50 to 20·38; and it will therefore require heating not up to 1300° merely, but to some higher temperature, so that the smaller quantity of air shall carry in with it the same gross amount of heat. In the present case this result may be approximately arrived at by raising the temperature in the inverse ratio of the reduction in quantity of the air, making the temperature 1371° instead of 1300°, or in the proportion of 21·50 to 20·38; and the dotted curve in Fig. 11 has been constructed on this principle, basing it upon the full line which shows the actual saving between 1100° and 1422°. The dotted curve having been carried on by continuing the same mode of calculation up to 2000° has been employed as a guide for prolonging the full line to the same extent, by observing the amount of its deviation from the dotted curve up to 1422° and allowing a proportionately increasing amount of deviation up to 2000°. The maximum temperature of 1422° at present reached on the full curve was the average worked at for three consecutive months, during which the coke consumed per ton of iron made, of the average quality of No. 3·82, was 20·10 cwts.; and when corrected at the rate of $\frac{1}{2}$ cwt. less per number up to No. 4 iron, for which the curve is constructed, this consumption is equal to 20·01 cwts. of coke per ton of iron.

It will be seen that the saving of coke by the use of blast at 1422° over that at 1100° is no less than $2\frac{1}{2}$ cwts. per ton of iron; and the saving from 1000° to 1422° is about 4 cwts. Such a saving as 4 cwts. of coke per ton of iron made amounts, upon a make from one furnace of 475 tons per week, to $475 \times \frac{4}{20} \times 52 = 4940$ tons of coke per year, which at 11*s.* 6*d.* per ton is a saving of £2840 per furnace per year. This is a point on which the writer wishes to lay particular stress, as an impression has been entertained that the use of a higher temperature of blast than is attainable in cast-iron stoves is of doubtful advantage. Above the temperature of 1422° however, the curve flattens so rapidly that the further saving attainable beyond that point up to 2000° amounts only to about 1¼ cwts. per ton of iron. At a temperature of blast of 1700° a saving of ¾ cwt. per ton is however probable, beyond that at the 1422°; and the writer has no doubt this can be obtained by means of a more perfect combustion of the gas, and a more powerful draught than in the present large stoves.

The full line in Fig. 11 is seen to turn rapidly upwards at lower temperatures than 1000°; and the writer has little doubt that at only 100° temperature of blast the consumption of coke would be as great as 43 cwts. per ton of iron. The rate of economy in consumption of coke, indicated by the dotted calculated curve, does not seem to apply to lower temperatures than about 1100°, where the question of the intensity of heat developed inside the furnace may probably interfere. When trying to make cold-blast iron in 1856, the writer found that the consumption of coke was as much as 23 cwts. per ton of iron more than in a hot-blast furnace, both furnaces being of the same size of 7100 cubic feet capacity. The experiment to ascertain the increase in consumption of coke for lower degrees of temperature of blast down to cold blast in large furnaces is too costly to warrant the attempt to discover the law of increase.

In considering the effects of increased capacity in the regenerators of the hot-blast stoves, and the large increase of capacity that is found necessary in them for absorbing the heat previously escaping to the chimney, the question arises whether the results thus obtained may not be assumed to be applicable to the corresponding effect that increased capacity of blast furnace would have on the economy of coke in the furnace itself. It may be thought that the chemical action in the blast furnace interferes with any such comparison; but it has to be considered that, in a furnace of only 7000 cubic feet capacity, chemical action in all probability does not extend into the throat of the furnace unless the ironstone be introduced at a temperature of above 400°, judging from the valuable experiments of Mr. Bell; and although 16,000 cubic feet capacity has been given as the extreme limit beyond which economy is doubtful, the writer thinks it probable that the absorption of sensible heat from the escaping gas at the furnace top will follow very much the same law as the absorption of heat in the regenerators; and the conclusion thus arrived at may form a suitable supplement to the former paper communicated by the writer.

It has been seen previously that doubling the capacity of the regenerator in the hot-blast stove, or increasing it from 4960 to 9550 cubic feet, effects a reduction of 216° in the temperature of the escaping gas, or reduces the average from 505° to 289°, (or $\frac{365+645}{2}$ to $\frac{244+334}{2}$); and the question is whether it may not consequently be inferred that doubling the capacity of the blast furnace, or increasing it from 20,600 to 40,000 cubic feet, would effect the same extent of reduction of 216° in the temperature of the waste gas, which is now escaping at 560° temperature. This would result in a saving of nearly 2 cwts. of coke per ton of iron, as seen by the following calculation. The quantity of gas generated in the furnace is 144 cwts. or 16,128 lbs. per ton of coke consumed; and taking the specific heat of the gas at 0·25 compared with water, the units of heat required to heat this gas to the extent of 216° are $16{,}128 \times 216 \times 0{\cdot}25 = 870{,}912$ units. Then 4028 Fahr. units of heat being developed by the combustion of 1 lb. of carbon into carbonic oxide, the total saving of heat is equivalent to a saving of $870{,}912 \div 4028 = 216$ lbs. of carbon, or nearly 2 cwts. of coke; and when about one ton of coke is consumed per ton of iron made, the saving would be nearly 2 cwts. of coke per ton of iron.

In the diagram Fig. 12, Plate 12, is shown the general conclusion at which the writer has arrived on the subject of the effect of capacity of furnace, coupled with increased temperature of blast; and he has to thank Mr. Bell for the valuable aid he has rendered in first laying down the curve indicating the effect of capacity of furnace, in a paper published by him last year: and that curve is shown in Fig. 12 by the dotted line B. In this diagram the horizontal dimensions represent capacities of furnace extending from 5,000 up temperature of the escaping gas; and consequently drew a straight line from the 30·80 cwts. of coke per ton consumed in the smaller furnace to the 26·50 cwts. in the larger furnace, presuming that a proportionate saving would be effected in a more than double size of furnace of 47,500 cubic feet capacity. The consumption of coke per ton of iron would then be reduced to 17·90 cwts.; but subsequent experience has enabled the writer to correct this error, and to ascertain that a temperature of at least 1422° of blast is required for accomplishing such a result, and a capacity of furnace of 40,500 cubic feet. The best result that can be looked for is a reduction in coke of $\frac{3}{4}$ cwt. per ton by a further increase in temperature of blast from 1422° to 1700°, and a further reduction of 2 cwts. of coke per ton by increasing the size of furnace to 40,000 cubic feet; which would together reduce the ultimate consumption of coke to 17$\frac{1}{4}$ cwts. per ton of iron made.

Another point to which attention has been drawn is the effect of increased heat of the blast upon the temperature of the gas escaping from the top of the blast furnace. In two similar furnaces of 20,600 cubic feet capacity each, the writer has been unable to find that any difference in the temperature of the escaping gas can be attributed to that cause. The average temperature of the blast during a fortnight was 1277° and 1135° in the two furnaces, and that of the escaping gas 606° and 586° respectively; and the driving of the two furnaces was equivalent to the consumption of 73 and 56 tons of coke per day respectively. The difference is so slight as to show that neither extra heat of blast nor extra driving has any prejudicial effect on the temperature of the escaping gas; and that the extra heat thrown into the furnace by the hotter blast is met by the extra duty to be performed in compensating for the diminished proportion of coke consumed per ton of iron made. So long as the materials charged into the furnace are cooler by some hundred degrees than the escaping gas, the writer believes a further economy is possible; and a greater benefit will be derived from increased size of blast furnace in the cases where the calcined ore is unavoidably cooled down to the temperature of the atmosphere before entering the furnace, than in the cases where it is charged whilst still hot from the calcining kilns.

Another direction in which the writer believes highly heated blast will be beneficial is in the anthracite blast furnace; and increased temperature of blast appears indeed to be the only probable means of overcoming the difficulties attending the use of that fuel. A highly heated blast would prevent the possibility of an ignited piece of coal becoming extinguished, so to speak, by a cooler blast; for the combustion of this dense coal being only superficial, unlike that of porous coke, it cannot be revived without great trouble and loss, if once the temperature sinks below that at which chemical action takes place.

In conclusion the writer wishes to draw attention to a further source of economy of fuel in the blast furnace, in which the principle of the regenerative stoves promises to be efficient. The ordinary process of calcining the ore has for its object simply the expulsion of the gaseous contents, which would interfere so prejudicially with the working of the blast furnace; and the addition of oxygen to the ore, which takes place in this process of calcining, has been disregarded as a disadvantage slight in amount, compared with the advantage gained by getting rid of the other impurities. The iron in the ore being originally in the state of protoxide in most of the ironstones that require calcining, contains 8 parts of oxygen for every 28 parts of iron; but the ordinary process of calcining has the effect of bringing the iron into the state of sesquioxide, and thus adding 50 per cent. to the quantity of oxygen previously contained in it. The consequence is that for every 28 cwts. of iron to be melted 12 cwts. of oxygen have to be removed, which has to be done in the blast furnace by no less expenditure than the consumption of $\frac{12 \times 6}{8} = 9$ cwts. of coke; this is equivalent to a consumption of 6·43 cwts. of coke per ton of iron made, for simply effecting the separation of the oxygen. Now if this duty can be removed altogether from the blast furnace, and if the deoxidation of the raw iron ore can be effected in separate closed chambers by the action of waste carbonic oxide from the blast furnace, heated by means of regenerative stoves to a temperature of 1000° to 1500°, the result will be the perfect reduction of the raw ore by the removal of the whole of its oxygen, leaving the blast furnace nothing to do but the melting work, no coke being consumed in the furnace for the removal of any oxygen from the ore. This result has now been proved by the writer by actual experiment, and so thoroughly is the deoxidation of the ore effected by this means, that in a period of five hours a lump of raw iron ore of about 5 inches diameter has been completely reduced throughout. In this direction it appears to the writer a further economy in the blast furnace is alone possible; and he is at present engaged in the preliminary experiments upon a tolerably large scale for testing the commercial value of the process.

(*Discussion at the Meeting on* 27*th January*, 1870.)

Mr. I. LOWTHIAN BELL observed that the great importance of any saving which could be effected in the consumption of fuel in blast furnaces must be at once apparent, when it was considered that at the present time nearly one sixth of the entire quantity of coal raised in this country was consumed in the manufacture of iron. There could be no question that the hot-blast stoves constructed upon Mr. Siemens' regenerative principle, as described in the paper, possessed the power of heating the blast far beyond the temperature attainable with the ordinary cast-iron stoves; and in fact the temperature of blast already reached in the actual working of the regenerative stoves greatly exceeded anything that cast-iron stoves would ever be able to accomplish. With respect however to the quantity of waste heat escaping from the hot-blast stoves, which had been stated to amount in those of cast-iron to as much as 1400° Fahr. while only about 400° was lost in the regenerative stoves, it was by no means an inevitable consequence of the use of cast-iron stoves that such a large quantity of waste heat should escape; and it was not to be considered that cast-iron stoves from which so much waste heat passed off to the chimney had reached the limit of economy they were capable of. At the Clarence Iron Works in the county of Durham he had had an arrangement in operation for two years past, by which the temperature of the products of combustion passing off from the cast-iron stoves was reduced to 400° before escaping to the chimney; this was effected by the use of an iron vessel filled with tubes, like a locomotive boiler, and the escaping heat from the stove was made to pass down through these tubes on its way to the chimney, while the blast to be heated was passed up over the outer surface of the tubes. By this preliminary heating there was no difficulty in raising the temperature of the blast with a comparatively small apparatus to about 400°, previous to its entering the cast-iron stoves.

The main question to be considered, in reference to the employment of the regenerative stoves, was the value in the blast furnace of the 400° or 500° additional heat of blast, obtained by the regenerative stoves as compared with the cast-iron stoves in general use. One advantage which had been ascribed in the paper to the regenerative stoves was the greater control their use afforded over the heat of the blast supplied to the furnace, thus giving the means of remedying many of the disturbances that always occurred to a greater or less extent in the smelting of iron. Inasmuch however as a blast furnace was always burdened to its utmost limit, whatever the temperature of the blast, he did not understand how any greater control was possessed over a furnace blown with blast at 1400° and burdened accordingly, than over one which was also burdened to its maximum extent although blown with air at only 1000°. Moreover the fluctuation actually allowed in the temperature of the blast with the smaller size of the regenerative stoves had been stated to amount to as much as 200° or 250° during a period of 50 minutes, without the furnace feeling the effect of this alteration in the driving; and it appeared to him therefore that, if such an extent of heat as 250° could then be dispensed with in the blast without any prejudicial effect, there could not be so much advantage in the higher temperature of blast obtained from the regenerative stoves as was attributed to it in the paper. With the blast heated to 1000° in the cast-iron stoves, it was not a question of 250° fluctuation in the temperature of the blast; for if the heat fell even 100° for any considerable length of time, there was an immediate indication of the change in the working of the furnace itself, and in a period of 50 minutes he should expect the furnace to give some indication of the loss of temperature in the blast if it amounted to as much as 250° during that time. In the comparison made between the cost of the regenerative stoves and those of cast-iron, the cost of £4000 per furnace seemed to him rather high for the cast-iron stoves, as there were not generally two reserve stoves required per furnace; and the addition of these would possibly explain the high amount put down for the cost of construction.

A comparison of the results obtained in different blast furnaces, from the employment of different constructions of hot-blast stoves and different temperatures of blast, was a matter beset with many difficulties, on account of the many interfering circumstances connected with the nature of the materials used in the furnace and the conditions of working of the furnace itself. Thus if the coke supplied to one furnace contained 2 or 3 per cent. more ash than in another, this not only diminished the heating value of the fuel to that extent, but also imposed the additional amount of work to be done in fusing the extra quantity of ash in the inferior coke. The ironstone and limestone were also liable to vary both in quality and in degree of calcination; and the furnaces themselves were liable to be affected in different ways by scaffoldings and other irregularities in their working. Taking all these circumstances into consideration, he thought the results already obtained and described in the paper, as to the economy of fuel consequent upon increased capacity of furnace combined with higher temperature of blast, were not to any important extent at variance with those which he had himself obtained from the different sizes of blast furnaces at the Clarence Iron Works. The curve that had been shown, representing the results which he had arrived at, had been obtained throughout the portion representing the smaller capacities of furnace, as well as that representing the larger capacities, from the same series of simultaneous observations, which had been made very recently upon furnaces at those works varying in capacity from 6,000 to 25,000 cubic feet.

In regard however to the further economy of fuel that was likely to be effected by a still further increase in the capacity of the present large furnaces, owing to the consequent reduction of temperature of the escaping gas, he did not see that any real analogy was furnished, as assumed in the paper, by the case of the regenerative hot-blast stoves, in which it appeared that by doubling the capacity of the regenerators a reduction of 216° had been effected in the temperature of the waste heat escaping from the stoves. From the experience already obtained in increasing the capacity of blast furnaces, he did not believe any similar reduction of temperature would result from doubling the size of the present large furnaces of 20,000 cubic feet capacity. For in some recent observations made at the Clarence Iron Works upon a succession of furnaces of increasing capacity, he had found that the temperature of the escaping gas, which at the smallest furnace of 6,000 cubic feet capacity amounted to about 845°, was reduced to about 610° at the next largest furnace of 11,500 cubic feet, being a reduction of 235°; a further reduction of 15° took place at the next furnace of 15,000 cubic feet, and a still further reduction of 8° at the largest furnace of 25,500 cubic feet, these temperatures being all obtained when the ore was used hot as it was drawn from the kilns. It was thus evident that by far the greater part of the cooling effect consequent upon increased capacity of furnace was produced by the first addition of 5,500 cubic feet to the capacity of the smallest furnace; and there seemed no reason for expecting that even in a furnace of 40,000 cubic feet capacity there would be any material reduction in the temperature of the escaping gas beyond that already attained in the present largest furnaces. The reason why a limit was thus reached in the temperature to which the escaping gas could be reduced, was to be found he believed in the circumstance that, in addition to the combustion taking place in the lower part of the furnace by the burning of the coke, there was also a species of combustion, though not intense, going on in the upper part of the furnace, almost to the top, consisting in the burning of carbonic oxide into carbonic acid which accompanied the deoxidation of the iron ore. This combustion continued to extend to a greater height above the tuyeres as the height of the furnace itself was increased; and to whatever height therefore the furnace was carried, the heat would always follow up, and prevent the temperature of the escaping gas at the top from being reduced much below that already reached. In the case of one of the furnaces at the Clarence Iron Works, which had recently been raised from 58 feet to 80 feet height, he had found on boring through the side of the furnace at the level of the original height that that part of the furnace, which before the increase of height had been comparatively cool, was now as hot, judging by the eye, as it had been previously at only 28 feet height above the tuyeres; and it appeared to him therefore that a further increase in the height of furnaces could not be anticipated to produce such an amount of cooling effect upon the escaping gas as would cause any material economy of coke in the furnace. The saving of fuel that could be effected by the interception of the sensible heat at present carried off in the escaping gas was limited by the actual amount of heat contained in the gas; and according to a calculation that he had made, the sensible heat carried off in the escaping gas from a furnace using 23 cwts. of coke per ton of iron made did not exceed that developed by the combustion of 3 cwts. of the coke consumed per ton of iron, which must therefore under any circumstances be the extreme limit of economy theoretically possible by interception of the heat in the escaping gas.

With respect to any further source of economy of fuel in connection with the chemical action going on in a blast furnace smelting Cleveland ore, he did not believe it probable that the relative proportions of the carbonic oxide and carbonic acid at present found in the escaping gas could by any means be so modified, as that a much larger proportion of the carbonic oxide should undergo perfect combustion into carbonic acid, and thereby develop a greater amount of heat within the furnace, producing a consequent saving of coke. For although the chief part of the reduction of the iron ore in the furnace was effected by the deoxidising agency of the carbonic oxide, yet the carbonic acid thus generated had on the other hand a strong affinity for metallic iron, in consequence of which it would, if nothing else interfered, re-oxidise the iron at the temperature existing in the furnace, becoming itself re-converted into carbonic oxide. The ascendancy of either of these two chemical reactions over the other was determined by the relative proportions of carbonic oxide and carbonic acid contained in the mixture of gas in the furnace; and in illustration of the mode in which a chemical reaction was determined by the relative quantities of the substances present, he might refer to the case of adding sulphuric acid to a solution of chloride of lead, when sulphate of lead would be precipitated; but on then adding hydrochloric acid in excess, the lead would be taken up again, the affinity of the sulphuric acid being overpowered by the presence of the hydrochloric acid in so much greater a quantity. The question was therefore, with regard to the mixture of carbonic oxide and carbonic acid existing in the blast furnace, what must be the relative proportions of these two gases, so that their antagonistic affinities should be mutually held in check, and that the escaping gas at the furnace top should be neutral in its action upon the iron ore. From an examination of the gas escaping at the several furnaces of different capacities at the Clarence Iron Works, and also at a still larger furnace of 33,000 cubic feet capacity at the Ferryhill Iron Works, he had found in each case that the relative proportions of carbonic oxide and carbonic acid were about 70 volumes of the former to 30 of the latter; and as all these furnaces were as usual burdened to the fullest extent compatible with their proper working, the escaping gas would of course contain the maximum proportion of carbonic acid; and he concluded therefore the relative proportions thus ascertained were those which were requisite for balancing the opposing affinities of the two gases. In order further to test this conclusion by the evidence of direct experiment, he had taken some of the calcined Cleveland iron ore that was supplied to the blast furnaces, and placed it in an iron vessel which was immersed in melted lead, and kept it uniformly heated to about the temperature of the escaping blast-furnace gas, which was somewhere between 770° and 810° Fahr., as the heat of the gas usually melted zinc but did not melt antimony. A current of mixed carbonic oxide and carbonic acid gas in varied proportions was then passed over the hot ore in the vessel for a period of several hours continuously, for the purpose of observing the relative effect in de-oxidising the ore; and it was found that, as soon as the proportion of 70 volumes of carbonic oxide and 30 of carbonic acid was altered to 69 and 31 respectively, the reduction of the ore by the current of gas was only the very slightest possible in amount; and when the proportion was further altered to 66 volumes of carbonic oxide and 34 of carbonic acid, complete reduction of the ore ceased. A further experiment was also made by passing a current of carbonic oxide gas alone backwards and forwards over the heated ore at different temperatures, so that it might take up the utmost possible quantity of oxygen from the ore; and it was then found that after many hours of this treatment, when the gas had entirely ceased to deoxidise the ore, the proportion of the gas remaining in the state of carbonic oxide had not been brought down lower than 70 volumes, with 30 volumes of carbonic acid. Now taking the case of one of the present large Cleveland furnaces working with a consumption as low as 23 cwts. of coke per ton of iron, and assuming the possibility of intercepting and saving the whole of the 3 cwts. of coke at present carried off as sensible heat in the escaping gas, there would still remain the further saving of as much as $2\frac{3}{4}$ cwts. of coke to be effected, in order to reduce the consumption of coke to the $17\frac{1}{4}$ cwts. per ton of iron that had been mentioned in the paper as probably capable of being realised. Such an extent of saving however he did not believe to be practicable by any modification which it was possible to effect in the relative proportions of the carbonic oxide and carbonic acid in the furnace; for a rough calculation of the quantities of these two gases evolved in smelting 1 ton of iron with $17\frac{1}{4}$ cwts. of coke showed that there would then be only 58 volumes of carbonic oxide to 42 volumes of carbonic acid. This was a greater proportion of carbonic acid, he feared, than would be found consistent with the operations of a furnace working Cleveland ore, the practical proportions of the two gases having been shown to lie within very narrow limits of variation from 70 volumes of carbonic oxide to 30 of carbonic acid.

In reference to the plan that had been suggested for effecting a saving of coke, by performing the deoxidation of the iron ore by the action of heated carbonic oxide gas, previous to charging the ore into the blast furnace, he did not see how it was possible for any economy to be obtained in this way. For the carbon of the coke in the blast furnace, with the exception only of the portion which combined with the iron, travelled up from the lower part of the furnace in the form of carbonic oxide, and at a sufficiently high temperature to effect the reduction of the iron ore contained in the upper part of the furnace; and the operation of reduction was consequently not the source of any absorption of heat. If therefore the carbonic oxide ascending in the furnace had not the ore to deoxidise, it would simply escape at the top of the furnace without doing anything, and would be so much coke wasted; and it accordingly appeared to him that there could not be any economy in going to the expense of a separate apparatus for heating up carbonic oxide gas to perform the deoxidation of the ore outside the blast furnace, when there was already the heat provided for effecting that operation within the furnace.

From these various considerations he regretted being unable to indulge in any hope that the present low consumption of 23 cwts. of coke per ton of iron in the largest Cleveland blast furnaces could by any means be reduced to such an extent as 5 cwts., so as to bring it down to the amount that had been named in the paper as the consumption to be aimed at.

Mr. E. A. Cowper remarked that the successive advances which had been made in the temperature of the hot-blast had always been attended by a saving of fuel in the blast furnace, the amount of the saving having been the greatest on the first introduction of the hot-blast by Mr. Neilson, by whom the temperature of the blast had gradually been raised to 600°. At the Thornaby Iron Works records had been kept for thirteen years past of the consumption of coke with continually increasing temperatures of blast in the same furnace; and every increase of temperature had been found to be attended with a saving of fuel in the furnace. At the time of the introduction of his regenerative hot-blast stoves, the temperature of blast obtained with the old cast-iron stoves was about 800°, and this had been raised at once to 1150° by the regenerative stoves, with a saving in the blast furnace of about 5 cwts. of coke per ton of iron. Some of the best cast-iron stoves could now heat the blast to 1000°, while the regenerative stoves at the present time were working regularly at 1420° ; and the average temperature recently obtained throughout a week's working of these stoves at the Ormesby Iron Works had been close upon 1600°. The saving of coke in the blast furnace with the 1420° temperature of blast was equal to 4 cwts. per ton of iron as compared with the blast at 1000° from the cast-iron stoves. He had no doubt that the average temperature of 1420° already maintained at Ormesby would become general, and thought there was every reason to expect the blast might be further raised with advantage.

The PRESIDENT moved a vote of thanks to Mr. Cochrane for his paper, which was passed; and the continuation of the discussion was adjourned to the next meeting.

(*Discussion at the Meeting on 28th April,* 1870.)

Mr. COCHRANE observed that in the discussion at the previous meeting it had been questioned whether by the use of the regenerative stoves any greater control was obtained over the heat of the blast than with cast-iron stoves, on account of the blast furnaces being always burdened to their utmost limit. With cast-iron stoves supplying blast to a furnace that was burdened to the maximum, it was certainly impossible to raise the temperature of the blast even to the extent of a few degrees only, when this might be desired for the purpose of counteracting any irregularities in the working of the furnace; but in the regenerative stoves it was always possible to increase the supply of gas, if desired, to a considerable extent beyond the regular consumption, and thus to heat the regenerators to a higher temperature and obtain a blast as much as 50° or 100° hotter than usual, so as to meet the requirements of the blast furnace. The higher temperature of regenerator was of course obtained at the cost of fuel, being accompanied by a greater loss of heat escaping to the chimney of the stoves; but this was a matter of no moment in comparison with the advantage of regularity in the working of the furnace. A variation of as much as 200° or 250° in the temperature of the blast during so short a period as 50 minutes occurred only with the stoves having the smallest capacity of regenerator; and in the more recent stoves of much larger capacity the extent of fluctuation was only about half as great during double the time. The heat of the regenerative stoves however was got up again to the full extent in the same length of time that they had been cooling; while the heat of the blast, supposing that it had dropped from 1500° down to 1250° during the time that one of the stoves was "on," was raised at once to the 1500° again, immediately upon turning on the freshly heated stove. Even if the fluctuation were as great in all cases as 250° in 50 minutes, he believed it would be generally considered preferable to submit to this extent of fluctuation with the regenerative stoves, for the sake of the attendant advantage which they afforded of increasing the temperature readily at any time in an emergency, rather than to have a temperature of blast that was nearly constant but always at its maximum possible, as was the case with the cast-iron stoves. The blast furnace was itself so vast a reservoir of heat that he was satisfied there was no fear of injury to the quality of the iron made, in consequence of the fluctuations in the temperature of the blast supplied by the regenerative stoves; and he had not found any detriment occasioned by that cause. The cost of £4000 had been spoken of as rather high for the outlay upon a set of cast-iron stoves for one furnace; but on the other hand the further working of the regenerative stoves showed that their first cost per furnace would be somewhat less than the amount given in the paper, as the regular make of the furnace to which these stoves were applied now exceeded 500 tons per week. With regard to the reduction of temperature which could be effected in the waste gas escaping at the blast-furnace top by increasing the height of the furnace, it would be evident that, in the case of furnaces into which the ore was charged hot as sometimes drawn from the calcining kilns, it would be impossible for the escaping gas to be cooled down much below 600°, however greatly the capacity of the blast furnace might be increased; but when the ore was charged comparatively cold, as was done at his own works, he did not think it unreasonable to assume that the same reduction which had been effected in the heat escaping to the chimney from the regenerative stoves, by doubling the capacity of the stoves, would also be effected in the escaping gas from the blast furnace by doubling the capacity of the present large furnaces; and if that were the case, the temperature of the escaping gas would then be reduced to about 350°. The theoretical saving of coke to be effected in the blast furnace by raising the temperature of the blast 500°, from 1000° to 1500°, had been estimated in a recent paper by Mr. Bell at only 1·59 cwt. per ton of iron made; but the actual saving effected at the Ormesby Iron Works by increasing the heat of the blast from 1000° up to 1422° had been found to amount to about 4 cwts. of coke per ton of iron made, the working of the furnaces continuing the same in all other conditions except temperature of blast.

With regard to the further saving of fuel possible by superseding the ordinary process of calcining the raw ironstone, he had since the last meeting further tested the plan which he had then named of reducing the raw ore by the application of the waste gas from the blast furnace, and had erected an apparatus capable of reducing 5 tons of ore at a time; and he exhibited specimens of the raw ore, the calcined ore from the ordinary process of calcination, and the reduced ore from the new process without calcination, the iron in the latter being magnetic, having no oxygen combined with it. By this process of preliminary reduction the operation to be performed in the blast furnace would be limited to simply melting the iron, instead of smelting it; and the mere melting of the iron would then require a smaller consumption of fuel than the reduction of the calcined ore in the blast furnace, to the extent of the fuel required for removing the whole of the oxygen contained in the calcined ore.

In the construction of the regenerative stoves described in the paper an important improvement had recently been effected by simply altering the arrangement of the successive courses of firebrick in the regenerators, in such a manner as to allow of cleaning out the whole regenerator at any time without the necessity for removing any of the bricks for the purpose. By this means the stoves were now enabled to use the gas direct from the blast furnace, without the need of any cleansing process for removing the dust from the gas before its combustion in the stoves; and the expensive apparatus that had been erected for purifying the gas for the stoves was therefore altogether dispensed with. The first cost of the regenerative stoves was thus reduced from nearly £6000 to less than £4000 per furnace.

Mr. E. A. Cowper said that, since the paper had been read by Mr. Cochrane at the previous meeting, great care and consideration had been given by Mr. Siemens, Mr. Cochrane, and himself, to the subject of the most economical construction and arrangement of the stoves in every detail; and this had resulted in an improved arrangement, which had enabled them to dispense with the previous dust-catchers for purifying the gas, and caused the stoves to do better duty per cubic foot of capacity, and also to be less expensive in construction. This was effected by arranging the successive courses of brickwork in the regenerator in the manner shown in plan and vertical section in Figs. 16 and 17, Plate 14, so that each course of firebricks was made up of a series of square compartments or boxes, Fig. 16, formed of split bricks; and the boxes in each alternate course were shifted slightly in a diagonal direction, so that the edges of the bricks on two contiguous sides of each box projected a short distance beyond those in the course immediately above and below, as shown in the vertical section, Fig. 17. The whole regenerator was thus made up of a collection of vertical passages, as shown in the vertical section, Fig. 14, Plate 13, the internal surfaces of every passage being broken by a succession of projecting ledges on opposite sides alternately, by which the current of gas or of blast through each passage was continually deflected and tumbled over, and was thereby made to expose constantly fresh surfaces to the brickwork; by this means the interchange of heat between the mass of brickwork and the currents passing through it was very quickly and completely effected, the heat being communicated to the bricks from the gas in combustion, when heating up the regenerator, and from the red-hot bricks to the air, when heating blast. This effect of tumbling the current over was produced at every course of bricks throughout the height of the regenerator; and the arrangement of the bricks shown in Figs. 16 and 17 had been adopted in preference to the old plan shown in Figs. 1 and 2, where the bricks of one course were made to stand immediately over the centre of the openings in the course next but one below; in the new plan the current passing through the brickwork was alternately caught by the projecting ledges upon two contiguous sides only, and in that way was much more effectually intermingled than if the obstructions to its passage were on the two opposite sides simultaneously.

Although the dust conveyed in the gas from the blast furnace had of course an opportunity of lodging on the numerous ledges formed by the projection of each course of bricks beyond the one above it in this mode of constructing the regenerator, yet at the same time a clear opening was left from top to bottom of each passage, large enough to admit of cleaning out the dust deposited upon the ledges and faces of the brickwork; and the cleaning could be done either by the insertion of a brush or by the use of a jet of blast of air or steam, without the necessity for removing any of the bricks for the purpose. By running the stove a little longer than usual with the cold blast on, the bottom of the stove, which was always comparatively cool, was further cooled down sufficiently for a man to enter with a flexible pipe having a nozzle, as shown dotted at A in Fig. 14; and a jet of blast under pressure could thus be blown up each passage in the regenerator, so as to blow out the dust at the top. If preferred, the stove could be still further cooled down until the blast pipe could be inserted at the top, as shown at B, Fig. 14, for cleaning the passages by a jet of blast from the top; and then by means of a worm-wheel and handle C, the pipe could be rotated in a circle for blowing down the passages all round the regenerator, the pipe being elevated or depressed for increasing or diminishing its range, so as to give the means of cleansing every portion of the regenerator.

The bond of the bricks in the new mode of constructing the regenerator was very strong and complete in every course of the brickwork; and it was impossible for any brick to fall down on its side, as each brick was held upright between two others standing at right angles to it and abutting against it in the centre of its length. The extent of bearing surface of the bricks in each course upon the course below was also much increased as compared with the old mode of setting the bricks; the bottom portion of the mass of brickwork was therefore capable of carrying a greater weight, so that the height of the regenerator could be increased beyond the present height of 26 feet without fear of injury to the lower bricks. The quantity of brickwork contained within the same cubic space was greater than in the previous stoves, while the extent of heating surface exposed was increased about 17 per cent. The friction of the stoves was very small, so that much less pressure was lost than with common cast-iron pipe stoves. Improvements had also been made in the details of the various valves and their connections; and the gas and air for combustion in the stove were now brought in through passages constructed within the bottom of the stove itself, as shown in the vertical section, Fig. 14, G being the gas entrance and F the air passage. This arrangement obviated the necessity for the expensive red-brick foundation and the iron pipe connections below the stove, which with the previous construction of the stoves had been required for the purpose of bringing in the supply of gas and air to the centre of the stove; and the stove stood upon a flat bottom without foundations. The improved stoves were therefore both more effective and cheaper than the previous ones; and a temperature of blast of from 1450° to 1500° could well be maintained by them. Seven of the regenerative stoves on the old plan had been in full work for some time at the Ormesby Iron Works, but these were now being altered to the new plan so as to avoid the use of dust-catchers altogether; and others were being erected at the

Barrow Hæmatite Iron Works and at Ebbw Vale, and were about to be adopted also in other parts of the country.

By dispensing altogether with the dust-catchers for purifying the gas previous to its combustion in the stoves, the first cost of the improved regenerative stoves was reduced to the extent of £1939, and did not exceed £3761, including royalty, instead of the £5700 given in the paper as the first cost. The corresponding annual cost therefore, reducing also the charge for renewal of bricks to £20 in the new stoves, would be only £208, as compared with £600 in the cast-iron pipe stoves, showing an annual saving of £392 per furnace. Adding this amount to the saving of £2840 per furnace per year, which had been shown in the paper to result from the use of the blast at 1422° furnished by the regenerative stoves as compared with the 1000° blast supplied by the cast-iron stoves, the total annual saving effected by the improved regenerative stoves amounted to £3232 per furnace, without taking into account any profit upon the extra quantity of iron made.

Mr. T. Whitwell gave a description of the regenerative hot-blast stoves designed by himself and in use at the Thornaby Iron Works, Stockton-on-Tees, and at the Consett Iron Works, near Durham. In these stoves, which are shown in Figs. 18 to 21, Plates 15 to 17, the regenerator is composed of a series of transverse vertical walls of firebrick B B, with narrow spaces A A left between; and openings are made alternately at the top and at the bottom of the successive walls for the passage of the current. The waste gas from the blast furnace entering at one side of the stove at G mixes with the air entering at D and E, and is ignited in the large combustion chamber F; and the heated current passes alternately downwards and upwards through the successive spaces left between the series of transverse walls, depositing its heat in the brickwork, and reaching the chimney flue C on the opposite side of the stove at a low temperature. The regenerator thus becomes highly heated on the side of the combustion chamber F, but remains comparatively cool on the chimney side; and when the gas and air valves and the chimney valve are closed, and the cold-blast valve H and hot-blast valve K opened, the blast passing through the regenerator in the contrary direction to the previous heating current takes up the heat from the successive firebrick walls, and becomes itself heated to the same high temperature previous to entering the blast furnace. A number of cleaning doors L L luted with fireclay are provided in the roof of the stove, through which scrapers with long handles are inserted for scraping off the dust brought over with the gas from the blast furnace and deposited upon the surface of the regenerator walls; and the dust scraped off is raked out through side doors N N at the bottom of the stove. By this means the gas dust is easily removed in a very short time, the cleaning being effected entirely from the outside, whilst the stove continues hot, without requiring to be cooled down at all for the purpose. In order to ensure the complete combustion of any portions of gas that may not have been entirely consumed in the combustion chamber F, a further supply of air is admitted through apertures J J in the transverse walls at the hot end of the regenerator; and the air channels being constructed within the thickness of the walls, the entering air thus becomes highly heated previous to issuing through the apertures and mixing with the current of gas, whereby the complete combustion of the whole of the gas is effected.

Mr. Whitwell said he had had a small pair of these regenerative stoves at work at the Thornaby Iron Works for four years, without any cleansing of the blast-furnace gas being required prior to its use in the stoves. A set of four large stoves on this plan had also been at work more than a year at the Consett Iron Works, and were those shown in Figs. 18 to 20, Plates 15 and 16. Each stove was 22 feet diameter and 25 feet high, containing 9000 square feet of heating surface in the regenerator. The width of passage between the successive transverse walls in the regenerator was 9 inches, and the area of passage $11\frac{1}{4}$ square feet; and the total length of course that the currents had to travel over in passing through the regenerator from one side of the stove to the other was 240 feet. Two of the four stoves were on blast at a time, while the other two were being heated up by the gas. The period of each shift was two hours, during which time two thirds of the total extent of heating surface in the regenerator became heated up to a red heat in the pair of stoves that were off blast, while in those that were on blast the extent of surface that remained at a red heat became reduced to one third of the entire heating surface. At no time therefore was there less than 3000 square feet of heating surface at a red heat in any one of the stoves, by which means such regularity was secured in the temperature of the blast delivered from the stoves that no difference could be detected in the working of the blast furnace from any fluctuation in the temperature of blast. The extent of firebrick that was at a red heat in the regenerator was seen at any time during the working of the stoves through the eye pieces I I, Fig. 18, inserted in each compartment of the regenerator.

The quantity of blast passing through each of the Consett stoves when in full work was 4000 to 5000 cubic feet per minute, and the heat of blast hitherto obtained with them was from 1350° to 1550° Fahr., as ascertained by Siemens' copper-ball pyrometer, the tuyere pipes being red hot. The temperature at the cold end of the regenerator, after heating up the stove for the period of two hours, was about 600°. The firebrick lining of the stove on that side was 14 inches thick; but on the opposite side, where the greatest heat was generated, the thickness of the lining was 22 inches, and the first transverse wall was built 9 inches thick, to increase its capacity for accumulating heat. To so great an extent did the walls of the regenerator absorb heat, that on one occasion when it was desired to cool down a stove, the blast was kept on for some hours till the hot end of the regenerator was apparently black; but on being laid off for an hour, the heat came out of the interior of the walls, and heated the stove red hot again; the blast was then turned on again for two hours, and this was afterwards repeated a second time, before the stove was completely cooled down. The walls exposed to the greatest heat in the regenerator were built of bricks composed of half ganister and half fireclay, and the rest were built of ordinary good firebricks. On first starting the stoves at Consett an argand burner had been constructed of Stourbridge clay within the gas inlet G, Fig. 18, fed by a 12 inch air valve, in order that the greatest heat might be developed by the combustion of the gas; this burner however fell to pieces the first shift, as it would not stand alternately being heated red hot when the stove was on blast, and then being cooled by the cold air entering through it for combustion of the gas in heating up the stove. An argand burner had therefore been made in the brickwork of the stove at D, and in addition the air inlets E and J were provided in the transverse walls at the hot end of the regenerator. This construction had answered well, and the heat thus obtained was so intense that the ganister bricks at the hot end of the regenerator became thoroughly glazed. The operation of cleaning any one of the stoves did not take more than nine hours altogether, and the stove then went on working again for two or three months, more or less, according to the quantity of dust deposited upon the walls of the regenerator. The total cost of construction of the stoves at Consett was not more than had been spent upon the most recent cast-iron stoves, whilst the heat of blast obtained with the regenerative stoves was much higher, and the economy of coke in the blast furnace proportionately greater. The firebrick stoves would indeed sustain a temperature of 2000°, if such a heat could be obtained by the combustion of the blast-furnace gas.

The working of the first set of these firebrick stoves at Consett had been found so satisfactory that a second set of four stoves on the same plan had recently been started at work there, each containing 10,600 square feet of heating surface; the length of travel of current through the regenerator was 250 feet, and the friction upon the blast in passing through that length caused a loss of pressure of $\frac{1}{16}$ lb. per square inch. For the purpose of more completely absorbing the heat from the gas before it quitted the stove, two of the stoves were provided with cast-iron plates 2 inches thick, hung on both sides of the two last or coldest walls, as shown at M in Fig. 21, Plate 17, which represented the most approved arrangement of the regenerator walls. The result of adding these cast-iron plates was found to be that in the stoves so supplied the gas escaped to the chimney at a temperature of 550°, being 50° lower than in the stoves not provided with plates; the temperature of the cold blast on entering the stove being 100°, the loss of heat in the gas escaping to the chimney was therefore 450°. In addition to these eight firebrick stoves now in operation at the Consett Iron Works, two more blast furnaces were being built there, which would be supplied with similar hot-blast stoves.

With regard to the saving of coke in the blast furnace, consequent upon the use of the hotter blast supplied by these regenerative firebrick stoves, the actual consumption during eleven months' working of the first set of stoves at Consett, with the blast heated to 1400° temperature, had been less than 18 cwts. of coke per ton of iron made, in a furnace 55 feet high, making 400 tons per week, and burdened with a mixture of two-thirds Cleveland and one-third hæmatite ironstone yielding 48 per cent. of metallic iron, the Cleveland stone being calcined. In an adjacent furnace of the same dimensions and burden, supplied with blast at 850° by cast-iron stoves, the consumption was $22\frac{1}{2}$ cwts. of coke per ton of iron; and in a similar furnace 5 feet higher at the Thornaby Iron Works, working on the same burden with blast at 1050° from cast-iron stoves, he had found the consumption to be from 21 to $21\frac{1}{2}$ cwts. per ton of iron made, thus confirming the correctness of the observations at Consett. The result therefore was a saving at Consett of more than $4\frac{1}{2}$ cwts. of coke in the blast furnace per ton of iron made, in consequence of an increase of 550° in the temperature of the blast. The make of pig iron during the last eleven months' working of the stoves at Consett had been upwards of 19,000 tons from the furnace supplied with the blast at 1400°; and of this quantity 75 per cent. had been grey forge iron and only 2 per cent. white iron, the burden of the furnace not having been changed during the whole of that period; while for twenty-six weeks at a time no white iron had been made.

In the new mode of constructing the regenerators in the stoves at the Ormesby Iron Works, by arranging the bricks in the manner now described and shown in Figs. 16 and 17, for the purpose of doing away with the dust-catchers previously employed, it appeared to him that there would be considerable difficulty in attaining the object aimed at, and that the numerous irregularities presented by the projecting ledges of the bricks would be found objectionable in the continued working of the stoves, by catching the dust carried in the gas; for he had found that when the dust once got a lodgment the accumulation increased like the growth of a fungus. The cleaning of the regenerator would be a matter he thought of more difficulty than seemed to be anticipated, because in the use of a jet of blast for the purpose the current of blast would not be effective he considered in clearing the dust off the projecting bricks: just as in boiler flues the air current did not search out corners, but passed them by in a curved course, leaving the soot deposited there in the undisturbed atmosphere. On this account he was led to anticipate that, though the stoves gave good results at first, they would fall off after they had got dirty; and for the same reason he expected it would be found necessary to employ a brush for cleaning the regenerators, in the manner that had been described; and that operation would involve the loss of time and waste of heat occasioned by laying off the stove and cooling it down sufficiently for a man to get inside and do the cleaning, which would interfere with the regularity of temperature in the blast supplied to the furnace. In the Consett stoves after a year's working the cleaning of each stove was completed in nine hours, without the stove being much cooled down, the same operation having been performed every two months previously during the year's working; even on the smooth vertical walls in these stoves the dust was found to stick at any parts where there was a roughness on the surface of the brickwork; and in the most recently erected set of the stoves particular care had therefore been taken to keep the faces of the walls as smooth as possible throughout the regenerator. The important difference between the two constructions of regenerative stoves now described was that in the one the whole ot the heat had to be taken up in the short distance of only about 26 feet height between the top and bottom of the regenerator: whilst in his construction the current had to travel a distance of 250 feet from the hot to the cold side of the stove, and in this great length of travel the heat was effectually taken up by the smooth walls of the regenerator, without the necessity for projections protruding from their surfaces into the current passing over them; and at the same time every part of the stove was easy to clean.

Mr. F. J. Bramwell remarked that, with regard to the fluctuation in temperature of blast which occurred with the regenerative stoves during the time that each stove was in turn supplying the blast, it had been explained that in practice this had not been found prejudicial to the quality of the iron made in the blast furnace; but it had occurred to him that, if any objection were still felt to the fluctuation which took place, it could readily be met by taking the minimum temperature as the constant limit, and cooling down the hotter blast to this temperature by the simple expedient of admitting a sufficient supply of cold air to mix with the hotter blast. Practically however it would probably be preferred to have the blast fluctuating from 1200° or 1300° up to 1450°, with the benefit of the higher temperature thus obtained at regular intervals, rather than to keep the heat always uniform at the lowest temperature, without taking advantage of the extra heat available in the fluctuation.

The possibility of effecting a further reduction in the temperature of the escaping gas by simply increasing the size of a blast furnace was a point which he had already called in question on the occasion of the former paper upon the same subject; and he considered there was an error involved in the assumption that mere increase of size must result in a further cooling of the escaping gas. It was the quantity of incoming material per hour by which alone the cooling was effected; and so long as this remained unaltered, and there had been time to effect the transfer of the heat from the gas to the incoming material, no increased cooling effect could be obtained however much the capacity of the furnace might be augmented. He was therefore unable to see how the large increase of capacity that had been found necessary in the regenerative hot-blast stoves, for absorbing the heat previously escaping to the chimney, could be taken as a sufficient ground for inferring that increased capacity of blast furnace would have a corresponding effect in reducing the temperature of the escaping gas. In illustration of the principle involved in cooling the escaping gas, the case might be supposed of an apparatus from which 2 lbs. of water per minute ran to waste at a temperature of 200°, while 1 lb. of fresh water per minute was supplied to the apparatus at a temperature of 60°, and was required to take up the heat escaping in the waste water. Then it was clear that the limit of the effect which it was possible to produce by any construction of the apparatus would be attained when the entering water was heated up to 200°; but this increase of 140° in the temperature of the 1 lb. of entering water corresponded to only 70° of heat abstracted from each one of the 2 lbs. of waste water, whereby the latter would be cooled down to the temperature of 130° only. From this it was clear that, although the water finally escaping at 130° was still at a much higher temperature than the fresh water entering at 60°, it would be impossible by any increase in the size of the apparatus to abstract more heat from the escaping water; because so long as the surface for the transfer of heat was large enough to raise the temperature of the entering water to 200°, no increase whatsoever in that surface would reduce the temperature of the escaping water any further; and the only way in which this object could be accomplished would be by increasing the proportion of the entering water. By making this water equal in quantity to that which was escaping, the whole heat of 140° above that of the incoming water might be abstracted by the latter; and then, and not till then, could the outgoing water be reduced to so low a temperature as that of the incoming water, or 60°. Applying therefore the same considerations to the blast furnace, it appeared that, although the materials charged into the furnace might still be cooler by some hundreds of degrees than the escaping gas, yet the further economy consequent upon reduction in the temperature of the gas could not be realised by any alteration in the size of the furnace itself, so long as the rate at which the incoming material was charged into the furnace remained the same; and it would only be by increasing the quantity of fresh material charged into the furnace per hour that any further cooling of the escaping gas could be produced. If indeed, to begin with, a furnace were not high enough, so that the escaping gas was not in contact for a sufficient length of time with the cooler materials in the furnace top to part with all the heat that they were capable of taking up from it, an increase of height would of course be attended with advantage in reducing the temperature of the escaping gas; but the illustration already given showed that a limit would be reached in the height of the furnace, beyond which no further increase in height could effect any reduction in the escape of heat from the furnace top; and unless it could be shown that such a limit had not yet been attained, it would be fallacious to calculate upon obtaining a further reduction of temperature in the escaping gas by merely increasing the height of the furnace.

Mr. COCHRANE observed that a very satisfactory confirmation of the economy of fuel obtained at his own works by the use of blast at 1422°, as compared with that at 1000°, was afforded by the results which had been mentioned of the experience at the Consett Iron Works, where it appeared that an increase in the temperature of the blast from 850° to 1400° had been attended with a saving of more than 4½ cwts. of coke per ton of iron made. The regenerative stoves at Ormesby with the new arrangement of the bricks for dispensing with dust-catchers had now been in use about three months, and had therefore not been long enough at work yet to require cleaning out; they were still working so well that he hoped they would go on for at least three months longer without cleaning, and he did not anticipate that there would be any difficulty in cleaning them effectually and readily in the manner that had been described. The dust deposited in the regenerator would be likely he thought to form short inclines upon the ledges of the bricks, and would equally serve to tumble the current over from side to side. In the Consett stoves, with the regenerator composed of transverse vertical walls, he thought the mode which had been adopted of introducing at successive stages the air required for combustion, instead of supplying the whole of it at once in the combustion chamber, was not one that would result in the development of the maximum heat from the burning of the gas; for on leaving the combustion chamber and entering the regenerator the gas that remained unconsumed would at once become cooled by contact with the brickwork, before meeting with the further supplies of air necessary for its complete combustion; and there might be some of the gas and air passing off to the chimney in the state of an unconsumed mixture, causing the loss of the heat that should have been developed by their combustion. The temperature of 2000° therefore, which it had been mentioned the regenerator walls would stand, if such a heat could be reached by the use of the blast-furnace gas, did not appear to him capable of being realised by that mode of burning the gas. In the Ormesby stoves however, where the whole supply of air for the combustion of the gas was admitted simultaneously and before any of the gas entered the regenerator, the temperature of 2000° had been nearly attained in the blast; for a blast of 1880° had been actually obtained at the tuyeres, which with 100° loss of temperature in the blast main gave 1980° as the temperature of blast in the stoves at that time. The blast he thought did not ever attain the full heat of the brickwork in the regenerator, which he believed in the hottest part was always some 200° or 300° hotter than the blast leaving it. The thickness of the regenerator walls in the Consett stoves seemed to him considerably greater than was desirable, judging from the circumstance which had been mentioned of a stove not becoming cooled down till it had been laid off and cooled by the blast for several hours, the process being repeated at successive intervals. The plan of introducing cast-iron plates in the stoves, for further cooling the gas before its escape to the chimney, was one that had also occurred to himself; but a trial of this plan in the stoves at Ormesby had resulted in its abandonment, as it had been found that the cast-iron was destroyed by exposure to higher temperatures than about 600°; and he did not think therefore that the cast-iron plates would be found to stand for any length of time in the Consett stoves.

In regard to the statement given in the paper of the comparative annual cost of the regenerative and the cast-iron stoves, he had considered it necessary in both cases to provide for the redemption of the capital within a period of about thirteen years, altogether irrespective of the renewal fund for the wear and tear of the stoves; for his own experience, during sixteen years' working of blast furnaces in the Cleveland district, had been that, in consequence of the very rapid advance made in the manufacture of pig iron, both by increased capacity of blast furnace, higher temperature of blast, and improvements in calcining kilns, it had been necessary in a period of thirteen years to sweep away nearly the whole of the plant previously used, irrespective of the state of repair it might be in at the time. With this experience of the very rapid and complete changes that had occurred, it seemed no more than a proper precaution that provision should be made for the possibility of similar innovations taking place during the next period of thirteen years; and the redemption fund had therefore been set apart to meet this contingency, by including in the annual cost of the stoves a charge of 7½ per cent. upon the original outlay. The renewals necessitated by the wear and tear of the stoves in regular working formed an independent item, and amounted in the case of the cast-iron stoves to the complete renewal of the entire stoves at the end of every ten years; because in that time the whole of the cast-iron pipes, which formed of course the great expense in those stoves, became entirely worn out, and rendered it necessary to pull down the stoves altogether and rebuild them. On the other hand the only portion requiring renewal for wear and tear in the regenerative stoves was the bricks in the regenerators, as the other parts of the stoves sustained no depreciation by wear and tear in working; and the renewal of the regenerator bricks formed therefore the only charge to be made upon the regenerative stoves, to correspond with the heavy renewal charge in the case of the cast-iron stoves.

As to reducing the temperature of the gas escaping at a blast-furnace top by increasing the height of the furnace, he concurred to a certain extent in the observations that had been made, believing that no further economy was possible from increased height of furnace, unless with the present proportion of incoming materials the temperature of the escaping gas exceeded that of the fresh materials by at least 200° or 300°; and it was only where this was the case that he looked for any advantage from increased height. The independent evidence of his own observations upon furnaces up to 20,000 cubic feet capacity, and of the results obtained by Mr. Bell in furnaces of from 12,000 to 25,000 cubic feet capacity, alike pointed to a further probable saving from still greater capacity of furnace, as indicated by the parallelism of the curves between 12,000 and 20,000 cubic feet capacity in the diagram, Fig. 12; and this view was confirmed by the results already obtained in the large Ferryhill furnace of 33,000 cubic feet capacity, where the temperature of the escaping gas had now been brought down to close upon 300°, the materials being charged cold into the furnace.

Mr. E. A. Cowper remarked that in the improved arrangement of the bricks in the regenerators of the hot-blast stoves he had not included the ledges of the projecting bricks in the calculation of the extent of heating surface presented by the regenerators, but had allowed for the ledges becoming covered with dust in the working of the stoves; and the mere lodgment of dust upon the ledges did not interfere in any way with the efficiency of their action in tumbling the passing currents over. The flat sides of the bricks, as regarded dust adhering to them, were in the same condition as the flat walls of the regenerators in Mr. Whitwell's modification of the stoves; and as the result in the Ormesby stoves was found to be a lower temperature of the gas escaping to the chimney than in the Consett stoves, it appeared that the improved arrangement of the bricks in the stoves at Ormesby was more efficient in taking up the heat from the gas than the flat flue surfaces in the regenerators constructed with a series of vertical transverse walls. Under these circumstances he hoped that the temperature of 1500° which was now being obtained in the blast with the improved stoves would be maintained as the average temperature with as much regularity as the former average had been maintained in the previous stoves before the alteration in the arrangement of the bricks.

Mr. T. Whitwell said that, in regard to the remarks which had been made respecting the mode of admitting the air for combustion in the Consett stoves, the plan adopted there in the first instance had been to admit the whole supply of air direct into the combustion chamber to mix with the gas; but the consequence of the admission of so large a quantity of cold air at 50° temperature was found to be that the combustion was not completed within the limits of the combustion chamber, and the maximum heat was therefore not developed until the gas had passed some distance into the regenerator. The result was that, when the blast was afterwards turned on, its first effect was merely to transfer the heat from the hottest part of the regenerator to the wall nearest the combustion chamber, which ought to have been the hottest part but was not so; and there had accordingly been a loss of heat in the blast with that plan of admitting the air. From this experience therefore he had been led to reduce the admission of cold air for mixing with the gas in the combustion chamber, enlarging at the same time the size of the chamber; and to admit the rest of the air through channels in the regenerator walls, whereby the air, instead of entering cold, was heated up to 1500° before mixing with the gas, and the greatest amount of heat was then developed by their combustion. The hottest part of the regenerator was thus brought close adjoining the combustion chamber; and when the blast was turned on, it became heated up to very nearly the full heat of the hottest brickwork in the regenerator. With this construction of the stoves the average temperature of blast was now regularly maintained as high as 1450°, and he expected a still higher temperature would be reached. The cast-iron plates which he had added upon the last wall at the cold end of the regenerator, for more completely taking up the heat from the gas before it escaped to the chimney, appeared to have their counterpart in the cast-iron girders supporting the mass of brickwork of the regenerator in the Ormesby stoves; these girders occupying the corresponding situation to the cast-iron plates, in the coolest part of the stoves, would be subjected to the same alternations of temperature, being exposed alternately to the hot gas quitting the regenerator and to the cold blast entering the stove at the same place. The first cost of the improved regenerative stoves at Ormesby appeared to amount to more than £3700 per furnace, while that of the Consett stoves did not exceed £3200; and the production of white iron, which had been mentioned as being reduced to 11 per cent. at Ormesby, had not exceeded 2 per cent. during nearly a year's working of the regenerative stoves at Consett.

Mr. COCHRANE explained that the instance given in the paper of the make of white iron at Ormesby was not intended to show the ordinary proportion of white iron that was made in working with the regenerative stoves; but the quantity of white iron had in that case been taken at a time when there were unusual difficulties to contend with, from the inferior quality of the coke supplied to the blast furnaces, and had been referred to for the purpose of showing the important advantage that was obtained by the use of the regenerative stoves as compared with the cast-iron stoves, in reducing the production of white iron under such circumstances: the actual make of white iron on that occasion was altogether exceptional. With regard to the comparative first cost of the regenerative stoves at Ormesby and at Consett, it had to be borne in mind that at the latter works the make of iron had been stated to be only 400 tons per week from a burden containing 48 per cent. of metallic iron, whereas at Ormesby the make was 500 tons per week from a calcined ore yielding only 40 per cent. of iron; and when these differences were allowed for, it would be found that the Ormesby stoves were the cheaper of the two.

Mr. H. F. ROSE enquired whether the quality of the iron made was found to be deteriorated in any way by the use of the hot blast at such a high temperature as 1500°.

Mr. COCHRANE replied that so far from the quality of the iron being deteriorated it was unmistakeably improved by the hotter blast, as evidenced by the greater difficulty of breaking the pigs in the casting bed.

Mr. G. ADDENBROOKE said he was glad the question had been asked about the quality of the iron made by the hotter blast, because the introduction of the hotter blast into the Staffordshire district had been mainly prevented by a prejudice against its use on account of some injurious effect it was imagined to have upon the quality of the iron, which was quite contrary to his own experience. If any furnace in the district were blown with blast at the high temperature now obtained by the regenerative stoves, he feared every little fault that was found with the iron or with the working of the furnace would be attributed to the extra heat of blast employed.

Mr. E. A. Cowper hoped that the results actually obtained with the hotter blast from the regenerative stoves would lead the Staffordshire district to follow the example of Middlesbrough in raising the temperature of blast and thereby improving the quality of the iron: the proportion of sulphur, phosphorus, and other impurities being diminished as the heat of the blast was increased.

The President remarked that, whatever might be the relative merits of the different stoves which had been described—whether of Mr. Cowper's original one, of his last improved one now described, or of the stove as arranged by Mr. Whitwell,—the highly important fact appeared to be clearly established that increased temperature of blast was attended with a decided economy of fuel, whilst the quality of the iron was decidedly maintained. How much further this increase of temperature could be carried with economy, and how long the improved stove using gas not previously purified would continue to work without cleaning, remained to be ascertained by further experience; and he hoped that the results would be found to be as satisfactory as there appeared reason to believe that they would.

The following paper was then read:—

ON A STEAM ROAD ROLLER.

By Mr. W. F. BATHO, of Birmingham, and Mr. T. AVELING, of Rochester.

The idea of employing steam power in place of animal labour for rolling down newly macadamised roads originated with the Chief Engineer to the Calcutta municipality, Mr. W. Clark, whose attention had been drawn to the subject by experiencing the expense and difficulty attending the employment of bullocks for drawing rollers over the Calcutta roads. A Steam Road Roller was consequently designed for him by Mr. Batho, which was sent out to Calcutta, and has done good work there during the last seven years, notwithstanding the defects in details attending a first and experimental design; and this steam roller has long since cleared its first cost by the saving in cost of its work compared with that done by rollers drawn by bullocks.

The principle of the machine is the use of three rollers arranged in a triangle, one roller on each side of the machine at the one end, and the third roller in the centre at the other end; the two side rollers are driven by the engine by means of pitched chains, and the centre roller is mounted in a turntable frame so as to swivel horizontally for the purpose of steering. The third roller is made wide enough to cover the intermediate space between the two side rollers; and the weight of the boiler and engine, which are vertical and placed in the centre of the machine, is distributed over the three rollers. The results of trials carefully made to determine the difference in cost of working with this steam roller as compared with the ordinary plan of rolling by bullocks, for rolling an area of road of 44,631 square yards, gave £146 4*s*. 6*d*. as the cost of steam rolling and £269 5*s*. 9*d*. as the cost with bullocks, being a saving of 46 per cent. in cost with the steam rolling, in addition to the economy arising from the much superior and more durable nature of the work done.

A steam roller on a different principle was subsequently constructed in France, which has now been extensively used for several years in Paris, and has thoroughly proved on a large scale the great practical value and economy of steam rolling in the making and maintenance of roads. This machine, which was described at a former meeting of the Institution (see Proceedings Inst. M. E. 1869 page 101), is carried wholly upon two long rollers, each one extending the full width of the machine, and both driven by the engine; and the steering is effected by sliding the axles at one end so as to throw them out of parallel when traversing curves.

The three-roller principle has been successfully carried out by Messrs. Aveling and Porter, in combination with their steam traction engine, with which the successful experience of many years' working had been previously obtained; and a number of steam road rollers of this make are now in use both in this country and abroad, having been at work from 1 to 2½ years.

This machine is shown in Figs. 1 to 5, Plates 18 to 21. The two side rollers A A are driven by the engine and connected to the same axle B, and the centre roller C is made in two portions, turning separately upon their axle for facility in steering, and carried in a turntable frame D for steering. Each portion of the centre roller is the same width as one of the side rollers, and the centre roller overlaps the side ones to a small extent. The total weight of the machine is distributed equally upon the two axles, so as to equalise the action of the rollers in working.

A single steam cylinder E is employed for driving, as in the traction engines, for the sake of simplicity and economy of construction; and with the use of intermediate gearing reducing the speed considerably, and a flywheel F upon the crank shaft for turning the engine by hand over the dead points when requisite at starting, the single cylinder has been found sufficient both in the road rollers and the traction engines. It is fixed on the front end of the boiler, surrounded by a steam jacket in direct communication with the boiler, as shown in Fig. 5, and having a dome on the top from which the steam is taken into the cylinder. The use of steam pipes is thus avoided, and priming upon steep gradients is prevented. From the crank shaft the motion is taken by spur gearing to a countershaft G carrying at its end the pitch-chain pinion; the bearings of this shaft are carried in curved slots H, Fig. 2, formed in the supporting brackets, so that the shaft can be raised when required in order to tighten up the slack that usually occurs in a pitch chain after some time of wear. The chain is covered up by a wrought-iron casing, and drives the chain wheel K, which is keyed upon the front axle B of the machine; the two driving rollers A are not keyed upon the axle, but are secured to it by the strong locking bolts I I, Fig. 5.

The turntable D, Figs. 2 and 3, carrying the centre steering roller C, is constructed with only two vertical carrying wheels J J, placed fore and aft, which allow it to swivel vertically to a slight extent, for the purpose of letting the rollers accommodate themselves to the convex surface of the road. The set of horizontal friction wheels L L guide the turntable horizontally in steering; and the machine is steered by a chain passing round the turntable, and worked by worm gearing from a handwheel M in reach of the steersman upon the foot-plate. The machine can be turned round by this means in a distance of little more than its own length; and it can be turned within its own length if required, by disconnecting either of the two driving rollers A A, which is done by withdrawing the locking bolt I that couples the roller A to the driving axle B, as shown in Fig. 5. A friction break, consisting of a wrought-iron strap upon a pulley N on the side of one of the driving rollers, and worked by a worm and screw P from the foot-plate, affords control over the machine, in case any of the gearing should give way. The boiler is horizontal and multitubular, placed longitudinally between the two driving rollers; the coal bunker and water tanks are placed at the sides of the firebox, containing a supply of coal and water sufficing for two hours' work.

The ordinary size of this road roller, such as is shown in the drawings, weighs 15 tons; and the total width over the rollers being 6 feet, this gives a compressing load of 2½ tons per foot width upon the road: the rollers are all 5 feet diameter, and the load is distributed nearly uniformly over them all. There are thirteen of these 15 ton machines now at work, several being in India and in the United States. Single machines have also been made of 20, 25, and 30 tons weight, which roll widths of 7, 8, and 9 feet respectively: the 25 ton roller has been working two years at Sheffield, and the 30 ton roller two and a half years at Liverpool. This 30 ton roller is 9½ feet total width, giving a compressing load in rolling of 3 tons per foot width; the steering roller is 5 feet diameter and the two driving rollers 7 feet.

The average cost of working the 15 ton rollers, under the ordinary conditions of this country, has been found from a number of different trials to be as follows, taking the actual cost of working, and adding an allowance for wear and tear and interest, but not including general superintendence charges, nor cost of water used. The daily working expenses amount to

	s.	*d.*	*s.*	*d.*
Wages to enginedriver 5*s.*, steersman 3*s.*	8	0		
Coke, 4½ cwts. at 1*s.*	4	6		
Oil and cotton waste	2	0		
			14	6
Allowance for wear and tear at 10 per cent., and interest at 5 per cent., on the cost of the roller £550, taking 250 working days in the year			6	7
Total cost per day			21	1

There has not yet been a sufficient length of experience in the working of these steam rollers for determining accurately the cost of wear and tear, but the above estimate is based upon the long experience that has been obtained with the traction engines.

The average work done per day is 2376 square yards rolled complete; and with the above total cost of working, 21*s.* per day, the work amounts to 9½ square yards rolled for one penny, including wear and tear and interest; or 13½ square yards rolled for one penny, for wages and fuel alone. Taking only 2000 square yards for the day's work, this gives 11½ square yards rolled for one penny of working expenses; or 8 square yards for one penny, allowing for wear and tear and interest. These results are confirmed by those obtained in the working of two of the same rollers in India, where the cost of working has amounted to 43*s.* per day for each machine in rolling a space of 7040 square yards, which gives 13½ square yards rolled for one penny, the same as in the previous statement.

A further development by Mr. Batho of the three-roller machine is shown in Figs. 6 to 10, Plates 22 to 24; in which the object has been to make the construction more complete and perfect, by adding to the complication and first cost, with the view of obtaining an increased amount of work from the machine. In this machine the two side driving rollers A A are placed upon separate axles B B, Figs. 8 and 10, which, as well as the axle of the centre roller C, are fitted with bearing springs S S, for the purpose of allowing the rollers to adjust themselves more readily to the curved cross section of the road, so as to apply the pressure more evenly throughout, and also for the purpose of easing the shocks produced by the passage of the heavy machine over the rough surface of the road. The adoption of bearing springs enables the machine to travel at a greater speed to and from its place of work, preventing the loss of time that occurs when this speed of travelling is limited to only about three miles an hour, as is usually the case in the absence of bearing springs. With the springs the roller easily travels to and from its work at a rate of four miles an hour. The springs have also an advantage in reducing the risk of crushing drains or breaking water pipes under the road that is being rolled.

A double-cylinder engine E E is employed, in order to give the means of starting in any position, and to afford greater facility for getting over the difficulty of one of the rollers sinking into a hole in the road. Each driving roller A is also provided with a separate driving chain K and a disengaging clutch T, so that either roller can be driven independently of the other, if desired in any emergency. In order to provide the means of tightening up the pitch-chains without interfering with the action of the bearing springs, the driving axles B B are carried in guides by means of radius links R R, Figs. 6 and 8, which have a screw adjustment at the outer end. For the disengaging clutches, Weston's friction clutch was at first employed, with the view of allowing either of the driving rollers to be partially or wholly disengaged while working, so that in turning sharp curves the inner roller could slip or remain at rest. In consequence however of practical difficulties arising from the heating of the clutch discs by the boiler, an ordinary solid clutch has since been adopted, and this has been found successful. A powerful lever break N is applied to the surface of the centre roller, for controlling the motion downhill when required.

This steam roller has been made of the increased weight of 25 tons, and 9 feet width, giving a compressing load of $2\frac{3}{4}$ tons per foot of width. The increase in total weight is for the purpose of accomplishing the rolling in less time, by a smaller number of courses over each portion of the ground, so as to get the work done more economically as well as quicker, by getting more done for the same cost of wages of the enginedriver and steersman working the machine. No difficulty has been experienced in this machine from the driving rollers slipping, and the adhesion is found sufficient to propel the third roller under ordinary conditions, even up a gradient of 1 in 9; when the road is smooth and wet, sand is required, as in starting a locomotive. The machine, which has been working in different situations during the last two months, rolls an area of 300 square yards of road complete per hour, and the consumption of coal is about 1 cwt. per hour; a supply of coal and water is carried sufficient for half a day's work.

The practice of leaving the metalling of roads to be consolidated only by the traffic passing over them has been so universal in this country, that rolling the roads, whether by horses or by steam power, is still generally looked upon rather as a refinement than as a source of economy in road maintenance. On the Continent however experience has led the French and Germans to consider rolling as the most important improvement ever made in the construction and maintenance of roads. The absence of any centralised authority in the road administration of this country, such as is customary on the Continent, has been unfavourable to the adoption of rolling here.

Road making is also subject to so many varying influences in the nature of the traffic, the locality, the quality of the metalling, the construction of the road, and the method of maintenance, that it is difficult to arrive at the exact amount of the economy resulting from rolling as compared with the absence of rolling; but from an average of extended experience in different countries, the economy attending the practice of rolling, even when horse rollers only are employed, is found to amount to as much as 34 per cent. saving in cost of metalling alone. Rolling prevents the metalling from being crushed piece-meal by the traffic, as is done when it is laid down loose without rolling; and the entire road is rendered better able to resist the injuries caused by moisture soaking in. A saving in labour in the construction or repair of a road is also effected by rolling, as the rolling allows of a greater area of metalling being laid down at a time, and a thicker coating of it when requisite; and instead of the stones being thrown down in small patches wherever defects show themselves in the road surface in course of time, the maintenance of the road can be carried out in a systematic manner. The force of draught required upon freshly laid unrolled metalling is as much as five times the draught for the same load upon a fairly good road surface, as ascertained by old established experiments; and this great difference shows the important saving which the users of a road derive from the adoption of rolling. This increase of draught also involves increased injury to a road from the horses' feet; so that in the ordinary case of rolling down a road by the action of the wheel traffic, this is not done, as commonly supposed, without cost to the maintainers of the road. On a well rolled road however, the wear that takes place is mainly that due to friction, as the vehicles passing over it are not jolted about with a continued series of concussions on the road surface, while the horses have less force of draught to exert, and the metalling is not crushed to pieces.

The drawbacks attending horse-rolling are however very great, especially in the case of a road with heavy traffic. The rolling interferes with the passage of vehicles, on account of the long string of horses required to drag the roller, and the consequent trouble and delay of turning round at the ends of the course; and the horses' feet disturb the metalling in a way that cannot be corrected by the succeeding passage of the roller. To roll a road completely with such a light weight as only a six-ton or even a ten-ton roller, which is the heaviest possible horse roller, it requires to be gone over a great number of times; and this weight of roller is much below that of the traffic in large towns, when calculated by the same measure of tons weight per foot width of the wagon wheels.

With the steam roller however all these objections are overcome: on account of its greater weight and the greater facility with which it is managed, it consolidates the metalling with much greater rapidity, and can be easily turned round, and worked up steep inclines; and it has been shown by experience in Paris that under proper management it can be worked without passing horses being frightened. As to the relative expense, the same work can be done by a steam roller at less than one half the cost of horse rolling; while in cost of metalling a considerable further saving is effected beyond that realised with horse rollers. In Paris the steam-rolled roads are found to last twice as long as those rolled by horses; and roads which formerly had to be rolled by steam power once every six months, and previously much oftener by horses, have been so much improved by this operation upon the successive layers that they now require rolling only once a year. This result has occurred too under a traffic that is annually increasing; and as the centre of the heaviest traffic in Paris is macadamised, and not paved as in London, the experience there obtained evidently affords a sound basis for comparison with the streets of the large towns in this country. Rolling has proved of great service not only for surface repairs, but also for consolidating the foundations in making new roads; and in Germany the horse roller is very generally used also for setting paving stones, instead of using the hand rammer.

In repairing a road, the expensive and troublesome process of picking up the surface in order to prepare it for the fresh layer of metalling, is effected by the steam roller with great expedition and economy, by simply fixing a number of short steel spikes in the working faces of the two side rollers, as shown dotted in Fig. 6, Plate 22; the rollers are prepared for the purpose by having countersunk holes cast all round their circumference at about 12 inches pitch, into which the spikes are fixed by nuts screwed on inside, as shown to a larger scale in Fig. 7. The rollers are readily changed from plain to spiked while the machine is out at work, about half an hour being sufficient for the purpose; and the spikes are all removed again in a quarter of an hour, the holes being stopped by wood plugs driven in when in ordinary work. An area of about 700 square yards of road is broken up by the machine per hour.

The usual process of road repairs with the steam roller is, after loosening the surface with the spiked rollers, to have it levelled in the customary way, and a layer of from 2 to 6 inches thickness of metalling laid upon a length of about 35 yards. The roller is passed two or three times over every portion of this length, working its way gradually across from one side of the road to the other, until the flat surfaces of all the stones are brought uppermost. A covering of one inch of sharp clean sand is then spread over the entire surface and well watered from a cart or hose, after which the rolling is continued until the stones are thoroughly bedded, and, as it were, concreted into their places; the surplus sand is then swept off, and the road is left in a finished durable state, the whole operation occupying usually about two hours for each length of 35 yards of road. The proportion of sand and water used varies in different places, different opinions being at present held as to the most desirable proportion for the purpose; but the value of sharp sand in preference to all other kinds of binding material is everywhere recognised, as is also the advantage of laying on no more of this material than suffices to fill up properly the interstices between the stones.

In places of crowded heavy traffic, such as in the streets of London, the evils arising from the constantly defective condition of macadamised roads as ordinarily made, and the frequent stoppages for repairs, have led to the substitution of stone pitching as the less of two evils, notwithstanding the serious objections to its roughness, slipperiness, and noise. But if such a street can be re-made in a single night without any stoppage of the day traffic, and can be started the next morning in a thoroughly finished and consolidated condition, as can readily be done by means of steam rolling, it becomes an important consideration whether the objections previously experienced with macadamised roads would not be got rid of, however frequently this re-making of the road might be necessary: particularly when the much greater durability of the steam rolled roads is taken into account.

The steam roller described in the paper, with double-cylinder engine and bearing springs, was shown in operation in the neighbourhood, upon a road undergoing repairs.

Mr. BATHO observed that the experience of several years' working of the steam road rollers in different parts of this country had shown beyond all doubt that there was a considerable advantage in the use of the steam roller as compared with rollers drawn by horses. There was some difference of opinion as to the size of the stones that should be used in the metalling, and his own impression was that larger stones would be better with steam rolling than the present size, as he considered the object to be aimed at should be to use a minimum quantity of binding material and a maximum of granite, so as to have the road surface composed of the hardest material possible. The plan too often pursued at present of laying stones down without either binding material or rolling resulted in the crushing of the stones by the traffic, the sharp edges being broken off by the wheels; but by the use of a roller the sharp edges of the stones were preserved, and with the addition of proper binding material they helped to form at once a hard homogeneous road with a smooth and even surface.

Mr. J. BALDWIN believed there was a strong feeling in favour of employing a steam roller for the roads in Birmingham, and he hoped it would not be long before one was in regular use in the town. With the present unrolled roads instances were frequent of injury to horses from passing over newly repaired portions of a road; and the defective condition of the road surface, even when a horse roller had been used upon it, became apparent after a shower of rain, by the water lying in numerous little pools in the hollows that were left. In the process of rolling, the horses' feet displaced the stones in front of the roller, and the roller was not able afterwards to roll them down again and make the surface really level, but left it in an uneven condition. On this account the steam roller was superior to a horse roller, as the rolling was done without the stones being disturbed at all by horses' feet during the process. An objection made to the steam roller was that its great weight would crush the stones, and they would not wear half so long; but the weight of the machine distributed over the width of the broad rollers was not actually so great per inch of width as the weight upon the wheels of heavily loaded omnibuses or carriers' vans. In Birmingham there was the advantage of being able to obtain in the neighbourhood an abundant supply of the small Lickey gravel, which was better than sand for using as the binding material on a newly macadamised road, and could be procured as cheap as sand for the purpose; and by the use of this material, together with the employment of a steam roller, he was satisfied the roads would become year by year so much improved that a great saving would be effected in the expense of maintaining them. The important advantages of rolling the roads had long been recognised, as he remembered more than sixty years ago that wagons having wheels upwards of 15 inches broad used to be allowed to travel upon the turnpike roads without payment of toll, in consequence of the beneficial effect which they produced upon the road by their broad wheels acting as rollers.

Mr. F. A. Paget said that, from some extensive statistics which he had collected upon the question of the maintenance and rolling of roads, he had found the saving effected by the use of horse rollers had been ascertained to be from 25 to 66 per cent. in the cost of the materials alone, without reckoning the great saving in labour. These were the results with horse rolling, the experience of which had already extended in some cases over periods of from thirty to forty years; and steam rolling would now double the duration of the metalling, in comparison with horse rolling, judging from the experience obtained in Paris, where steam rolling had been extensively employed for seven years and was found to be attended with a saving in material of 50 per cent. over horse rolling. By those who had to pay for the maintenance of the roads, the question of saving in cost of material was the one mainly considered; but another important advantage of road rolling was that the force of draught required upon a properly rolled road was only about one third of that upon an unrolled road, while the draught upon the loose metalling of a newly macadamised road which had not been rolled was actually five times as much as on a thoroughly good smooth road. With this combined saving in cost of maintenance and in draught, the system of steam road rolling if generally adopted would have the effect of covering the country with universal cheap tramroads that every one could use, without the necessity for the present expenditure of as much as £10,000 per mile in some instances for the construction of special tramroads. It was in the case of London that the importance of the saving to be effected by steam rolling was most particularly apparent, on account of the magnitude of the sums now spent upon the maintenance of the roads there. Upon the 2000 miles of macadamised and paved roads comprised within the thirty-nine districts into which London was divided, the sum of £300,000 had been expended in the year 1861 for the entire maintenance; and during the subsequent years this amount had continually increased, until in last year it had reached as much as £800,000. This great increase in expense was to be attributed to the increased extent of the paved roads, all the roads within a radius of two miles from St. Paul's being now paved with granite paving at a cost of about 18*s*. per square yard. Both the paving blocks and the macadam employed in London were better and more expensive than those used elsewhere, the metalling of the macadamised roads being composed of Guernsey granite, which cost 16*s*. per cubic yard when broken up into five-ounce pieces ready for laying on the roads. In places of the heaviest traffic the destruction of the macadam was very rapid, and only a small portion of the total expense was for labour; in

Piccadilly the whole annual cost of repairing the macadamised portion kept up by the St. George's vestry was £1384, of which £1359 was the cost of the metalling alone. Taking into account only that the duration of the roads would be doubled, as in Paris, by the use of a steam roller, he had found the result would be a clear saving in London of at least £140,000 per annum in the cost of metalling alone. The improved condition of the roads rolled by steam power would also greatly enhance the value of the vast amount of capital already invested in horses and vehicles; within a radius of 4½ miles from Charing Cross it was estimated there were nearly 72,000 horses and 31,000 vehicles, representing together a capital of probably not less than four millions sterling; and the improvement of the roads and consequent saving both of horses and vehicles were benefits that would be shared alike by all classes of the community.

Mr. E. YATES thought the particulars given in the paper as to the advantages of the steam road roller were thoroughly convincing in respect to the importance of road rolling. In regard to the plan of fixing spikes in the rollers for breaking up the road surface in preparation for a layer of new material, he had observed in one instance that after the passage of the spiked rollers it had been necessary for the men to use their picks all over the surface of the road, in order to bring it into a fit state for receiving the new material; and he enquired whether it was intended for the spikes of the new roller to finish the whole breaking up of the road, so as not to require any work with the picks afterwards. He asked also whether the addition of the bearing springs in the improved roller would be sufficient to prevent the breakage of gas and water pipes by the passage of the heavy machine along the road; the damage being done he supposed by the weight of the machine itself, he did not see how it would be obviated by the addition of the springs, unless at the same time the weight of the roller were reduced.

Mr. J. ROBINSON considered the bearing springs now added to the steam roller were a very great improvement, and would certainly prove of great value in preventing the machine from breaking gas and water pipes in its passage over the roads. The shocks occasioned by the passage of the heavy roller over inequalities in the road surface would be effectually absorbed by the bearing springs; and though the weight of the machine was not diminished, it was prevented by the springs from coming down with a violent blow upon the surface of the road in passing over uneven places. On this account a roller which might be so heavy as to break the gas and water pipes, when not mounted on springs, would by the intervention of the springs be enabled to travel over them without doing them any damage. Only recently he had noticed a lorry loaded with pigs of cast iron driven along a paved street with such remarkably little noise that his attention had been attracted to the unusual quietness of its motion, and he found the reason to be that it was mounted on springs, which absorbed the shocks arising from the jolting of so heavy a load over the rough street. Besides preventing damage to pipes laid below the road surface, the bearing springs added upon the steam roller would also be beneficial to the machine itself, causing a saving in wear and tear by mitigating the injurious effects of constant jolting.

Mr. BATHO said his object in adopting the bearing springs for the steam roller had been that just explained, namely to obviate the danger of the heavy machine breaking the pipes laid in the road; and for the same reason he had also considered it preferable to place each roller upon a separate axle with separate bearing springs, so that the two driving rollers should be able to adapt themselves independently to the transverse curvature or unevenness of the road surface, whereby the strains upon the machine and the shocks upon the ground in passing over inequalities would be less than if the two rollers were both fixed upon one axle. There was also less probability of the rollers skidding, when each was on a separate axle and driven independently. Another advantage was that the adoption of separate axles for the driving rollers allowed of a considerably wider machine being used, causing a saving in wages, because the same man could drive the wider machine as readily as the narrower one. The greater rate at which the machine fitted with bearing springs could travel to its work was also an advantage of much importance, and the increased width enabled the rolling to be done quickly during the night in streets where there was great traffic in the daytime; and the quicker the rolling could be finished, the better was it both for the machine itself and for the road too.

The spikes fixed round the circumference of the rollers for breaking up the road surface previous to metalling were not intended to do away with the ordinary process of picking the surface up by picks, but only to make a number of holes into which the picks could afterwards be inserted for loosening the intermediate surface; and so greatly did the passage of the spiked roller facilitate the work of breaking the surface up, that it was found the amount of labour was reduced to only about one twentieth of that ordinarily required in picking up a road surface for metalling. In a street in Birmingham an area of 1200 square yards had in this way been broken up in half an hour; and the efficiency of the roller for this purpose was almost more apparent than even its advantages in rolling a newly macadamised road.

Mr. J. Sadler would have been glad to have the results given of the experiments that had been made in Birmingham with steam road rollers, as to the economy realised by their work, instead of the results in other towns only being referred to.

Mr. T. Walker thought there could not be any doubt as to the advantage of using a steam roller; for wherever there was heavy work to be done and steam could be made to do it, the work was better done by steam power than by any other means. Three steam rollers had now been tried in Birmingham, and he thought some one of these ought now to be adopted and employed permanently in the town, as it was known that each of them would do the work in a substantial and lasting manner. He had seen the steam roller in operation in Liverpool and elsewhere, and was desirous to see it used also in Birmingham, being satisfied that any steam roller, even though not the best that could be obtained, was vastly superior to the horse rollers at present employed.

The President said he had that day seen in operation the steam roller described in the paper, with double-cylinder engine and bearing springs, and he did not think there could be any question as to the great advantages attending the application of steam power to the rolling of roads. The same principle might also he thought be extended with advantage to the lighter rollers used for agricultural purposes, enabling farming operations to be performed more rapidly and efficiently; and he did not see why steam power should not be used for many purposes where horses were now employed.

He moved that the discussion should be adjourned to the next meeting; and proposed a vote of thanks to Mr. Batho and Mr. Aveling for the paper, which was passed.

The Meeting then terminated.

PROCEEDINGS.

2 and 3 August, 1870.

The Annual Meeting of the Members was held in the Great Hall of the Mechanics' Institution, Nottingham, on Tuesday, 2nd August, 1870; Thomas Hawksley, Esq., Vice-President, in the Chair.

The Chairman expressed the great regret of the President, which would be shared by all present, that he was unfortunately prevented by severe illness from presiding at the meeting of the Institution in Nottingham.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened, and the following New Members were duly elected:—

MEMBERS.

Alfred Alexander,	Cirencester.
John Alley,	Moscow.
William Irving Armstrong,	Wolverhampton.
Charles Fanshawe Atkinson,	Sheffield.
John Blair,	Aarhuus, Denmark.
William Bury,	Liverpool.
Nathaniel Clayton,	Lincoln.
Matthew Gray,	London.
Francis Leaver Guilford,	Nottingham.
George Edward Harding,	London.
Henry Kinsey,	Nottingham.
Henry Nye,	Paris.
Thomas Powell,	Rouen.

William Radcliffe, . . .	Sheffield.
James Vincent Russell Swann, .	Moscow.
George Benjamin Wright, .	Walsall.

ASSOCIATE.

Edwin Arthur Wright, . .	Wolverhampton.

GRADUATE.

Michael Holroyd Smith, . .	Halifax.

The following paper was then read:—

ON SELF-ACTING MACHINERY FOR KNITTING HOSIERY BY POWER.

BY MR. ARTHUR PAGET, OF LOUGHBOROUGH.

The date at which the appliances for Knitting have been brought within the limits of machinery, strictly so called, is very recent; and the subject of knitting and of machinery for that purpose has been so much out of the pale of mechanical science, that some explanation is required as a preliminary in the present paper, to show the nature of the structure of knitted web. This is illustrated in the magnified diagrams, Figs. 15 and 16, Plate 29, which represent a back view and side section of knitted web; and it will be seen that one thread here does duty for both warp and weft, and is itself woven direct from the bobbin into a web consisting of rows of loops, the loops in each row being drawn through those in the row immediately preceding. In hand-knitting this action is performed either by the ordinary knitting pins or by the "crochet hook," and in both cases each loop is separately and individually made complete; or, as in the case of the old framework-knitter's frame, each row of loops is made by a hand apparatus and then drawn through the previous row at one operation.

In most knitted articles it is necessary that, during the process of making the web from the thread or yarn, it should also be shaped at the same time that it is made. This is one great peculiarity of the hosiery manufacture, that shaped wearing apparel, comprising the numerous descriptions of under-clothing, is produced direct from the yarn at one operation of the machine, and without the intervention of the tailor or milliner; and the weaver of calico, cloth or other such fabrics, will hardly realise at once the enormous amount of detail which this peculiarity involves in the manufacture of hosiery, to suit all the different shapes and qualities required, entailing as it does the necessity that the machines employed shall be easily adapted to make articles of very great variety of shapes, thicknesses, and degrees of elasticity. The framework-knitter's old hand-frame, which has for so many years been almost the only apparatus commercially employed in manufacturing knitted wearing apparel, though now doomed to the same fate as many other clever contrivances of former years, is even yet in the Midland district the means of producing probably the larger part of the hosiery made. One of these old hand-machines is exhibited to the meeting for the purpose of illustrating the advance now made in the application of mechanism to the hosiery manufacture.

The Self-acting Machine for Knitting Hosiery by Power, which forms the subject of the present paper, is shown in general elevation and section in Figs. 1 and 2, Plates 25 and 26; and its construction and action will be better understood by confining the attention at first to the five primary parts which actually manipulate the thread in knitting it into web. These are shown full size in Fig. 3, Plate 27; and enlarged details are given four times full size in Figs. 5 to 12. The five primary parts are the Thread-Tube delivering the thread, the Sinker, the Needle, the Knocking-over Bit, and the Coverer. The action will first be explained of these five primary parts which manipulate the thread, and then of the secondary parts which effect the movements of the primary parts.

Knitting.—In the *making* of the web, as contradistinguished from narrowing or shaping it, the four first-mentioned of the above primary parts are employed, the coverer being used only when narrowing; and the successive stages in the process of making the web are shown in Figs. 17 to 24, Plate 30. The needles are all arranged side by side in a row as wide as the greatest width of the article to be knitted, as seen at N in Figs. 14 and 15, Plate 29; and above and between the needles are the sinkers S, each of which has its lower end or tail projecting downwards through the space between the needles. Above the needles is a projection or neb upon each sinker, Fig. 3, under which the thread is laid upon the needles by the thread-tube T traversing from side to side in the machine. The knocking-over bits K are arranged between the needles, one behind each sinker, their tops projecting slightly above the needles.

To commence working, a piece of knitted web is generally put upon the needles, with one loop on the stem of each needle N, as in Figs. 15 and 16; these loops are placed immediately behind the tails of the sinkers S and in front of the face of the knocking-over bits K, as in Fig. 17, Plate 30. The thread-tube T is then caused to make its traverse, laying the thread across the stems of the needles and underneath the nebs of the sinkers. Each sinker then descends in succession, or technically speaking "sinks" between the needles, the neb carrying down with it a loop of the thread; in this way a series or row of loops is formed, hanging on the stems of the needles, as in Figs. 18 and 14. The curve of the sinker-incline A, Fig. 14, which depresses the sinkers in succession as it traverses across the machine, is made of such a form that each sinker has fully completed its descent or "sunk its loop," before the neb of the next one comes down upon the thread. If this were not done, the thread would have to be drawn by the one sinker under the next one, while the latter was pressing on the thread; and as most hosiery threads are only very slightly twisted and consequently of very little strength, the thread would be injured by such a tension upon it. When the thread-tube T arrives at the end of its traverse, that is, when the required width of needles has been passed over, it descends and carries the thread down between two of the needles, as in Fig. 18, thus forming the loop on the last or selvedge needle without the aid of the sinker. The whole row of needles then retire or are drawn backwards, as in Fig. 19; and the ends of the hooks, technically called the "beards" of the needles, pass over and enclose the loops just formed by the sinkers.

The presser bar B, Figs. 13 and 20, now descends; and being made with grooves in its face through which the sinkers slide, the walls of these grooves press the points of the beards of the needles into the grooves in their stems, as seen in Fig. 20 and dotted in Fig. 8. The needles then retire still further, the new loops being still round the stems and under the beards of the needles, while the old loops now slide over the beards, as in Fig. 21; and the presser bar B is raised again as soon as the points of the beards have fairly entered the old loops on the needles, Fig. 21. The needles, still continuing to retire, draw the new loops which are *under* the beards up to the old ones which are *over* the beards; and then draw the new loops *through* the old ones, the latter being held against the face of the knocking-over bits K, as in Fig. 22. When the needles next advance, the old loops drop down below the heads of the needles, as in Fig. 23; this process is technically called "knocking-over the loops," and to ensure its being thoroughly done and all the loops well levelled in length, the needles are made to retire a second time, and thus draw the loops again tight against the face of the knocking-over bits. The needles then advance and the sinkers S descend, as in Fig. 23, so that the tails of the sinkers keep the loops behind them, while the needles continue to advance and their stems slide forwards through the new loops, as in Fig. 24, until they have reached again their former position, shown in Fig. 17. The thread-tube T now ascends between the same two needles between which it previously descended; and all the parts assume the position they were in before the commencement of knitting this first row of loops, as in Fig. 17, with the exception that the thread-tube is now at the other side of the machine. The same process is then repeated, the thread-tube now laying the thread across the needles from left to right, instead of from right to left as before; and thus the knitted web is successively increased by adding a row of loops, technically called a "course," alternately from left to right and from right to left, one course being added for each revolution of the cam shaft of the machine.

Narrowing.—For narrowing the knitted web in order to shape or fashion it, the simplest method would seem to be merely to stop the traverse of the thread-tube, one, two, or more needles earlier than before, and so make the web narrower on one or both sides. But if this were all that was done, the loops on the needles so left beyond the traverse of the thread-tube would in the next course be pushed off the needles and dropped; and, as will be seen from the diagram

Fig. 15, a dropped loop or stitch in knitted web "runs down," as it is termed, and produces a defect or kind of elongated hole commonly called a "ladder." To avoid this defect it is necessary to secure the loops which would thus be pushed off the needles and dropped; and the method employed to effect this is identical, as far as the construction of the web is concerned, with that used for many years by the framework knitters. This method consists in narrowing the web at certain intervals by two needles at a time, the intervals or number of courses between each narrowing being regulated so as to produce an approximation to the curve desired, as for instance in the leg of a stocking so as to fit correctly. The word approximation is used, because of course if the web knitted were rigid and inelastic the shape produced would really be narrowed by a series of sudden steps, instead of being a suitable curve; but as the knitted web is thoroughly elastic, the steps are not perceptible, and the result is a well-shaped stocking or other article. The essential principle of the narrowing is that the two loops to be narrowed are removed from two needles at the edge of the web, and are transferred to the two needles next to them and nearer to the centre of the machine. Thus these two needles have each two loops upon them, and one of the loops in the next row of knitting is then drawn through each of these pairs of loops, exactly as before described in making web; by this means the loops which would otherwise have run down are held secure. But as this pair of doubled loops produces a slight thickening and distortion of the web wherever they occur, and as it is considered a point of great importance to avoid even the slightest irregularity of the selvedge, it is usual to transfer four loops instead of only two, and to move them all four a distance of two needles sideways, as before described; thus the two loops nearest the selvedge are left single and perfect, and the thickening is produced in the next two loops, as shown at D in Fig. 15. Instead of moving four loops, any other number might be moved, and instead of moving the loops two needles sideways at a time, they might be moved only one needle at a time; but the general rule for ordinary work is four loops moved and two needles narrowed.

The transfer of the four extreme loops on either side of the knitted web, for the purpose of producing a narrowing, is effected by means of the Coverers, shown at C in Figs. 3 and 13; these are small pointed instruments having each a groove on the underside, as shown in Figs. 5 to 7, Plate 27, by which the needle head and beard can be covered. Four of these coverers, fixed at the same pitch or gauge as the needles, are carried in a small slide E, Figs. 13 and 34, which slides upon the rocking slide-bar F extending across the machine in front of the row of needles; there is one of these slides at each end of the bar, the four coverers being opposite to the four outer needles on each side of the knitted web. When a narrowing is to be made, the coverers advance together towards the needles, until the points of the coverers C reach a little over the points of the beards of the needles N, as in Fig. 25, Plate 31; at the same time the sinkers S are lifted up. The coverers are now depressed at the points or tilted downwards, so that their points enter into the grooves in the stems of the needles; and they cover and press down the beards of the needles, as in Fig. 26. The needles and coverers then retire together, and the points of the coverers enter into the loops on the needles, Fig. 26. The loops then slide along the coverers as these continue to retire with the needles, being held forwards by the face of the knocking-over bits K, until the heads of the needles have retired behind the face of the knocking-over bits, as in Fig. 27; in this way the loops are slipped off the needles and transferred entirely to the coverers, on which they hang as seen in Fig. 27. The coverers are next elevated at the points or tilted upwards as in Fig. 28, so as to be clear of the needles and the tops of the knocking-over bits. They are now traversed laterally, or technically speaking "shogged," a distance of two needles towards the centre of width of the web, carrying with them the four loops they have picked up; and they are then depressed again upon the heads of the four needles over which they have now been brought, as in Fig. 29. Of these four needles the two outer have no loops under their beards, while each of the two inner ones has a loop hooked under its beard, as shown in Fig. 29. The sinkers S now descend, and the needles and coverers together advance; and the loops being held back by the tails of the sinkers, slide along the coverers as these are withdrawn, Fig. 29. The needles and coverers continue to advance together, until the loops slip off over the points of the coverers, as in Fig. 30, and are thus again transferred from the coverers to the needles. The coverers then retire to the position they were in originally, as seen in Figs. 13 and 34. This narrowing operation is performed usually on both selvedges of the web simultaneously; and at the same time the length of traverse of the thread-tube T is reduced to two needles narrower on each side of the machine, in the manner that will be subsequently described.

The means by which the secondary parts effect the movements of the five primary parts that have been described will now be generally explained.

The Thread-Tube T, Fig. 3, is shown in connection with the secondary parts actuating it in Fig. 13, and also in Figs. 31 to 35, Plates 32 and 33. It receives its traversing movement sideways to and fro across the machine by means of the driving slide G, Figs. 31 and 34, which slides along the top bar of the machine, Fig. 1. This slide has a cord attached to it at each end, and the two cords are led round guide pulleys and brought together at the left-hand side of the machine to a double-grooved pulley D, Fig. 1, called the "drawing-across" pulley, which is carried on the left end of the cam shaft H of the machine. In Figs. 36 to 40, Plates 34 and 35, are shown side views of the pulley, and in Fig. 39 a back view. Each cord has an iron bob at the end, and in Fig. 36 the right-hand cord-bob is shown just ready to be taken hold of by the notch J that is made across the two grooves in the pulley. As the pulley revolves, this notch takes hold of the cord-bob and thus draws round with it the cord, as in Fig. 37, thereby drawing also the driving slide G, Fig. 31, towards the right-hand end of the machine. Meanwhile the other or left-hand cord-bob has been drawn up to the periphery of the pulley, Fig. 37, but not until after the notch has passed it, so that it is not taken hold of during this revolution. When the pulley has revolved further, as in Fig. 38, a stud projecting from the side of the tongue J, which is hinged in the circumference of the pulley, impinges on the fixed incline L bolted to the frame of the machine, Fig. 39; the tongue J is thus raised, and throws out or disengages the cord-bob, which falls down into the trough below, thus stopping the traverse of the slide G that is drawn by the cord, Fig. 31. During the next revolution of the drawing-across pulley it will draw the left-hand cord, and then disengage it in the same way when the traverse of the slide is completed. Thus during alternate revolutions the slide driving the thread-tube is drawn across the machine from left to right and then from right to left. The position of the fixed incline L, Figs. 36 to 39, is adjustable for disengaging the cord-bobs at the proper point, according to the length of traverse that is required for the slide G. On occasion of a narrowing having to be made, as the slide G is then required not to make its traverse, the disengaging lever M, Figs. 39 and 40, is brought up against the side of the drawing-across pulley, so as to raise the projecting stud of the tongue J and hold the tongue up through the length of the arc of the lever, as shown in Fig. 40; it thus prevents the notch in the pulley from catching the cord-bob in this revolution of the pulley. When the narrowing is completed, the lever M is withdrawn again, as shown by the dotted lines in Fig. 39, and is then clear of the stud on the tongue J.

The slide G driving the thread-tube T, Figs. 31 to 35, Plates 32 and 33, carries an incline I projecting in front, called the thread-layer incline, which drives with it across the machine the horizontal thread-slide Q, sliding on the bar P that extends across the machine. This horizontal slide carries a vertical slide R holding the thread-tube T; and the incline I drives the horizontal slide Q by bearing against the inclined top of the vertical slide R, Fig. 31, which is held up in its place by a latch D until near the end of the traverse. The latch is then unlatched by an incline J projecting from the thread-layer stop H; but by means of a peg L projecting from the vertical thread-slide R and resting upon the raised ledge M on the stop H, the vertical slide R is still held up until the moment that the horizontal slide Q is stopped by the stop H. At that same moment the peg L clears the ledge M; and the vertical slide R with the thread-tube T is then driven down between two of the needles, as shown in Figs. 34 and 35, by the incline I acting upon the inclined top of the slide R. For the return traverse of the horizontal thread-slide Q, the thread-tube and its vertical slide R are lifted again by the thread-layer lifting-bar U, Fig. 34, which extends all across the machine; this lifts the slide R, in whatever position across the machine it may happen to be, by means of the peg L projecting forwards over the bar. The lifting-bar U is carried by the two front arms of a rocking shaft, which has a third arm projecting backwards and acted upon by a cam on the cam shaft.

The Sinkers S, Fig. 3, are free to slide up and down, and are held sideways at their upper ends in grooves in the front and back bars P and W, Figs. 13 and 34. In the operation of knitting they are driven down or "sunk," each in succession, by the curved sinker incline A, Figs. 34 and 35, Plate 33, which is carried by the traversing slide G; the incline A, as it traverses, drives the sinkers down by acting on the upper edge of that portion of them which is between the two grooved bars P and W, as shown in Figs. 14 and 34. The descent of the sinkers thus follows closely the laying of the thread by the thread-tube as it traverses across the machine. Each sinker is held from falling, before the sinker incline drives it down, by a sinker-spring V, Fig. 34, which latches it up in that position by taking into the notch at the back of the sinker near the top, as shown in Fig. 13; and this same sinker-spring assists the sinker in falling at the end of its descent, by bearing against the inclined top of the sinker, as shown in Fig. 34. The sinkers are stopped at the end of their descent by the sinker lifting-bar X, Figs. 13 and 34; and they are all simultaneously lifted when required by the same bar, which is itself lifted by a rod at each end, passing down to a rocking shaft that is acted upon by a cam on the cam shaft. The sinkers are all lowered simultaneously when required by the sinker lowering-bar Y, which lowers them by its under edge bearing upon the projection in front of each sinker; this bar is lowered by two rods and a rocking shaft and cam, in somewhat the same manner as the sinker lifting-bar is raised.

The Needles N, Fig. 3, are fixed in a bar Z at the back, Figs. 13 and 34, and rest in front on the upper edge of the knocking-over bar which holds the knocking-over bits K; the needles slide on the knocking-over bar as they retire and advance. The retiring and advancing are effected by a rocking shaft Z, Fig. 2, Plate 26, the two upper arms of which are jointed to the back of the needle-bar, and the one lower arm is acted upon by a cam on the cam shaft H. The presser-bar B, Figs. 13 and 34, which in descending presses the beards of the needles down into the grooves in their stems, as shown in Fig. 20, receives its movements from the same rods and rocking shaft that move the sinker lowering-bar Y, the pressing motion of the bar B being effected by a second cam.

The Narrowing movements of all the primary parts except the coverer are produced by the same mechanism that effects the movements for knitting the web, but by a different set of cams on the same shaft. The movements of the coverers, in advancing, depressing, elevating, and withdrawing them, are effected by the arrangement shown in Figs. 1 and 2, Plates 25 and 26, consisting of a slide-bar F carried between centres, which allow the coverers C to be depressed and elevated at the points by means of a lever A; this lever is also shown in Figs. 45 to 50, and is actuated by the cam B. The centres carrying the slide-bar F, Figs. 1, 2, 13, and 34, are themselves carried in a rocking frame, which allows the coverers to be advanced and withdrawn by a cam for that purpose.

The Coverer Slides E, Figs. 13 and 34, which are also shown by the dotted lines E in Figs. 31 and 35, Plates 32 and 33, are traversed or shogged along their slide-bar F by the pin B carried in the lower part of the thread-layer stop H at each side of the machine. When the coverer slides are in position to be shogged, the pin B abuts against their side and pushes them along the slide-bar towards the centre of width of the machine. The thread-layer stops H are themselves shogged along the bar P on which they slide, by the action of the shogging ratchet C, Figs. 31 to 33; this works as a compound knee-lever into the ratchet-teeth in the slide-bar P. Thus when the joint C is lifted, as shown in Fig. 33, the ratchet takes a tooth; and then when the joint is lowered, as in Fig. 31, it shogs the thread-layer stop H along the bar P, and thereby shogs also the coverer slide E and the thread-layer slide Q carrying the thread-tube T. The traverse of the thread-tube is accordingly stopped two needles earlier on each side of the machine by the stops H. The lifting of the shogging ratchet C, Fig. 33, is done by the bar O, Figs. 32 and 34, which is actuated by a cam and lifts the pin of the ratchet joint; it holds the joint up until the coverer slides E upon their rocking frame have been brought into line with the pins B, and the joint is then lowered again by the bar O, whereby the coverer slides are shogged laterally through the required distance.

The Shape and Length of the article that is being knitted are regulated by an endless pitch-chain of peculiar construction, which though believed by the writer to be little used in England is frequently employed in France, and is called there "chaine Vaucanson" after its inventor the great engineer Vaucanson. This chain, shown at C in Figs. 41 and 42, Plates 36 and 37, is shown full size in Figs. 43 and 44, Plate 38. It is drawn towards the cam shaft H of the machine, Figs. 41 and 42, through the distance of one link for each revolution of the shaft, by means of the eccentric and ratchet D. Immediately above the chain is the narrowing handle E, the lifting of which into the position shown by the dotted lines during one revolution of the shaft H will cause the machine to make a narrowing during that revolution. The lifting of this narrowing handle can be done by hand, if desired, but is usually effected by a special link N inserted in the chain. This link, called a narrowing link, has on its upper surface a projecting incline, Fig. 43, which when drawn under the narrowing handle lifts it, as shown in Fig. 47, Plate 40, and thus makes a narrowing in the knitting. Another sort of link S is also shown in Figs. 43 and 44, called a stopping link, having an incline projecting at its side; this link is inserted in the chain wherever it is wished that the machine shall be stopped, and the stoppage is effected by the stopping link unlatching the sliding handle F, which carries the tightening pulley G. This pulley pressing against the driving gut of the machine gives the tension requisite for driving it, as shown in Fig. 41, the stopping handle being latched in that position by the projecting lug I on its side catching against the guide in which it is carried, as shown in Fig. 42; but when the stopping link cants the handle, as in Fig. 44, the catch I is liberated, and the driving gut is thereby slackened and the machine stopped. Each plain link in the pitch-chain C represents therefore one row of loops or one course in the knitting, and each narrowing link represents a narrowing, and each stopping link represents the completion of the piece to be knitted.

The Change of all the movements of the machine from making web to narrowing is accomplished by having two different sets of cams mounted on a tube, which is free to slide lengthways upon the cam shaft, but is driven round with it, as shown in Figs. 45 to 50, Plates 39 to 41. The several cams are so arranged in their distances sideways along the sliding cam-tube M that when the cam-tube is at the right-hand side of the machine, as shown in Figs. 45 and 46 and the back view Fig. 49, the set of cams for web-making acts on the various levers and arms of the rocking shafts, while the set of cams for narrowing passes clear on the right-hand side of them. But when the cam-tube M with its two sets of cams is traversed along the cam shaft H about $\frac{3}{4}$ inch towards the left side of the machine, as shown in Figs. 47, 48, and 50, then the set of cams for narrowing act in their turn upon the levers and rocking shafts, and thus make a narrowing. When the cam-tube is traversed back again to the right-hand side of the machine, the making of web is resumed, and is continued until the cams are again traversed to the left. This longitudinal traversing movement of the cam-tube is effected by an arm P, attached to the cam-tube M, and driven round by the cam-tube driver Q which is secured upon the cam shaft H. Below the arm P are a pair of helical inclines K and L, Figs. 49 and 50, the upper one K for traversing the cam-tube from right to left, and the lower one L for traversing it back from left to right. This pair of helical inclines are attached to the axle of the narrowing handle E, Figs. 41 and 42, so that when the handle is raised they are lowered and *vice versâ*. Thus when the narrowing handle is lifted for narrowing and the helical inclines lowered, as in Fig. 47, the cam-tube arm P will be acted upon by the upper incline K, as shown in Fig. 50, and the cam-tube M will be traversed to the left hand, as in Figs. 48 and 50, causing the several narrowing cams to come into action upon their respective levers. If on the next revolution of the cam shaft H the narrowing handle is lowered for web-making and the helical inclines raised, as in Fig. 45, the lower incline L will then come into contact with the stud J on the cam-tube arm P, as shown in Fig. 49, and will traverse the cam-tube M back again towards the right-hand end of the machine, as in Figs. 46 and 49, and the cams for the web-making movements will come into operation. So long as the narrowing handle is not raised again, the stud J will continue to pass below the upper helical incline K and alongside of the lower one L, as in Fig. 49, and the cam-tube will not be traversed; but whenever the narrowing handle is lifted, the web-making movements will be stopped and a narrowing will be effected. There are altogether twelve cams upon the cam-tube M for producing the various movements required in knitting and in narrowing; and of the three cams shown in Figs. 45 to 50, the cam B acting on the lever A produces the elevation and depression of the coverers in narrowing, by tilting the coverer slide-bar F, Figs. 13 and 34, upon the centres on which it is carried in the rocking frame; while the pair of cams S S acting alternately upon the lever T, Figs. 45 to 50, produce the vertical movements of the presser-bar B and the sinker lowering-bar Y, Figs. 13 and 34.

In conclusion, with reference to the speed of working of the self-acting knitting machine now described, as compared with the older methods of knitting, it may be taken that a skilled knitter with ordinary knitting pins will knit about 60 stitches or loops per minute in knitting the leg of a stocking. A skilled framework-knitter will with his hand-frame knit on the same work about 5,400 stitches per minute; whereas a girl will on the same work attend to three of the self-acting machines now described, each making 50 courses per minute of $13\frac{1}{2}$ inches width and 20 stitches per inch, the three machines together thus making 40,500 stitches per minute. A large number of these self-acting machines are now in use, having been in successful operation for several years.

Mr. Paget exhibited in operation three specimens of the self-acting knitting machine, arranged for different descriptions of work, together with some sets of samples explaining the successive stages in the manufacture of several different articles of hosiery, both those made by the machine as described in the paper, and others requiring some modifications of the machine. He showed also at work one of the ordinary hand-knitting machines still extensively employed for hosiery manufacture.

The Chairman observed that the self-acting machine now exhibited, of which so interesting and elaborate a description had been given in the paper just read, appeared to him to effect by mechanical means a very perfect imitation of the manual operation of knitting; and although probably little known at present in this country beyond the hosiery district of the Midland counties, he thought the machine was destined to affect very greatly the commerce of Nottingham and the hosiery manufacture generally, and he considered there were a great many other purposes to which this machinery would in some modified form be applicable with advantage.

Mr. H. Chapman mentioned that a large number of these knitting machines had been made in France, and he believed they were giving general satisfaction.

Mr. Paget remarked that one difficulty which he had experienced at first in getting the machine to work had arisen from the speed of the sinkers being the greatest at the end of their descent, and from their having then to be stopped dead by the sinker lifting-bar. The consequence of stopping them so suddenly had been that, although made of steel carefully rolled and hardened, they were at first broken in half at the rate of 50 or 60 sinkers per day in a single machine, owing chiefly to the suddenness of the stopping action. This difficulty had subsequently been got over by shaping the curve of the sinker incline somewhat differently, and by also making the thread itself act to some extent as a buffer to break the force of the fall; and he had now had machines running for four months without breaking a single sinker.

The CHAIRMAN observed that an important mechanical question respecting the breakage of the sinkers was, at what point did they break; and he enquired whether they all broke in one place, in consequence of the particular way in which the shock was distributed, or whether they broke in different places. He asked also where the manufacture of the needles, coverers, and sinkers for these machines was carried on.

Mr. PAGET replied that the breakage of the sinkers occurred generally in different places in different machines. In some machines the tails of the sinkers broke off just below the neb, while in others the breakage took place at the shoulder just above the neb, and in others again at the shoulder at the top end of the sinkers, the steel having probably been originally strained and injured at those places in punching the sinkers out. The sinkers were made by steel-pen makers, and the only difficulty experienced in making them was that as they were much longer than pens they were more liable to warp in the hardening process. This difficulty had at first been a serious one, causing the loss through warping to be as much as 30 per cent. of the sinkers made; but he believed the loss had now been reduced to not more than 10 per cent. The needles and coverers for the self-acting machine were made like those for all other stocking frames, and were obtained from the makers of ordinary hosiery needles. There was no peculiarity at all in the needles, except the way in which they were held in the needle-bar. For the ordinary hand-knitting frames the needles were cast in pairs in lead, and held in a wrought-iron frame in the machine; and when one needle was injured, it was requisite to take out the two. In the self-acting machine the needles were single and were separately inserted in a brass bar and secured by a top bar, as shown in the drawing (Fig. 13, Plate 28), and were put in with a slight amount of bend upwards, so as to be sprung down when the covering bar was fixed in its place, thus causing it to hold them all quite firmly; and any one of the needles could be taken out and replaced, without disturbing the adjacent needle on either side.

Mr. F. J. Bramwell observed that the fact which had been mentioned of the breakage of the sinkers taking place differently in different machines, but similarly in the same machine, and always at the parts where there was a sudden change of form, seemed to corroborate views which he had himself expressed elsewhere about the influence of form upon the strength of material, a sudden change of form at any point being conducive in his opinion to fracture at that point. Hitherto there had been two ways he believed of manufacturing stockings, the one by the hand-frame such as was now exhibited, in which the shaping of the work was duly performed as the knitting progressed: and the other by the use of self-acting machines, which had the advantage of continuous and very rapid action, but had the disadvantage that they were incapable of effecting the shaping, so that in reality they only produced a knitted fabric in the form of a parallel pipe, which being divided into lengths was used for the legs of stockings. Each length was afterwards caused to assume the shape of a leg by being placed upon a board of the required form, and subjected to heat; but the first washing of such a stocking brought it back to its original parallel form. In the self-acting knitting machine now described however, in consequence of the admirable and complete manner in which the various movements had been worked out, the articles were manufactured in their correct final shape, which was retained permanently as in hand-frame work. In this machine the shaping of the articles during their manufacture by the very ingenious process of mechanical narrowing was regulated by a pitch-chain, which appeared to be in its action a very simple kind of Jacquard, having a link of the chain for each course of the knitting or for a narrowing or a stopping, just as there was a change of card in a weaving machine for each passage of the shuttle. But as the number of motions required in the knitting machine was limited to the two simple changes for narrowing and for stopping, there was no need for the complexity of the Jacquard with a variety of perforated cards, the changes being effected with the use of the simple chain now shown, by merely inserting in it at the proper places the "narrowing links" and the "stopping links" that had been described, forming a true Jacquard in principle but of very elementary construction.

Mr. Jeremiah Head enquired what was found to be the durability of the narrowing pitch-chain in the machine, and also of the rope drawing the traversing slide across the machine, and what materials the chain and the rope were made of; and also whether crucible steel castings had been used in the construction of the cams or other parts of the machine, and if not, whether that material would not be applicable with advantage. He asked also what was the cost of one of the machines, complete for work.

Mr. Paget replied that there was some difficulty in answering the enquiry about the duration of the pitch-chain, as he had not seen one worn out yet; in the early machines the narrowing and stopping links in the chain were not case-hardened, but were made of soft iron, and wore away in consequence; but these were now all made of malleable cast-iron and case-hardened, and he had never met with any of the chains that showed any signs of wear, though they had now been working for twelve years in some of the machines. In addition to the stopping link in the chain for stopping the machine on the completion of the piece of work in process of knitting, a second stopping link was inserted in the chain when the machine was employed in knitting stockings, for stopping the machine as soon as the knitting of the toe was commenced, in order that the attendant might then change the thread bobbins on the machine, as it was usual to knit the toe of the stocking with thicker yarn than that employed for the leg. The ropes drawing the traversing slide across the machine were made of hemp, very much like ordinary sash lines; their wear averaged about twelve months, and the cost of replacing them was only about a penny each. The various cams in the machine were all made of ordinary cast iron, as at present he had not been able to get cast steel of a sufficiently reliable quality for the purpose. He had one machine which had been running eight years, and, with the exception of replacing one defective casting, the cams had not required anything during that time beyond re-touching with a file. When a sufficient degree of perfection was attained in the production of cast steel for small articles, he should certainly adopt it for the cams, for the sake of its greater durability. The cost of one of the machines of the size exhibited, capable of knitting web 13½ inches wide and 21 gauge, that is, containing 21 leads of two needles each in 3 inches standard width, or 14 needles per inch, was about £30; but the cost varied considerably with the fineness of gauge and the width of the machine, and the external fittings required in any particular case.

Mr. C. HAWKSLEY enquired whether there had been any intermediate stages of improvement between the ordinary hand-knitting machine exhibited and the self-acting machine described in the paper.

Mr. PAGET replied that an intermediate improvement upon the ordinary hand-knitting frame had consisted in adding a cam shaft at the back for performing all the movements required in knitting straight parallel work; this caused the stockings to be made parallel in the leg, and the foot also was of a very unsatisfactory shape; an arrangement was therefore added at the same time for stopping the machine when required, and making a narrowing by hand, after which the web-making was resumed and continued till the next narrowing. Of those machines there were a considerable number in use at the present time; but he believed the larger part of the hosiery produced in the Nottingham and Leicester district was still knitted by hand frames, these being made however a good deal wider, so as to be worked by men who could reach over a larger width and knit two stockings at once side by side in the frame. Another improvement made about sixty years ago, long before Nottingham had become engaged in the manufacture, consisted in knitting the stockings in circular courses, and consequently parallel in the leg; this invention had been introduced by an ancestor of his own, who had produced in that way the first piece of hosiery ever made by steam power.

The CHAIRMAN proposed a vote of thanks to Mr. Paget, which was passed, for his paper, and for the excellent opportunity afforded for seeing the working of the machines exhibited to the meeting.

The following paper was then read:—

ON THE MODE OF WORKING AND THE MECHANICAL APPLIANCES EMPLOYED IN THE MIDLAND COALFIELD.

BY MR. GEORGE FOWLER, OF NOTTINGHAM.

One of the principal advantages of holding the annual meetings of this Institution in different localities is the opportunity that is afforded for the examination of the engineering operations of the district, and particularly those in which the same end is accomplished by very different means in different localities. The annual meeting of last year was held in the Northern Coalfield, and much was seen on that occasion of the modes of work there practised. The present meeting takes place at the extreme end of the Midland Coalfield; and as coal is the food of mechanical power, and as the extraction, hauling and winding of it to the surface are all engineering operations, it will be felt that the subject of this paper is a suitable one for the present occasion.

Working.—The initial problem in all coal mining is the mode of dealing with the load of the different strata which overlie the coal seams, and which impose a statical pressure upon the unwrought seam in the ratio of its depth below the surface. There are two principles upon which this question can be dealt with; and both of these when applied in practice may and do receive very numerous modifications. In the early days of coal mining there does not appear to have been any intercourse between different mining districts; and it is somewhat remarkable that, whilst in some places the leading idea in the most ancient workings appears to have been to work the coal in galleries and support these by leaving pillars on either side of them, in others the coal was removed entirely, and the necessary openings or working places along the edges of the solid seam were secured by taking advantage of the resistance which the overlying rocks oppose to vertical fracture or shearing. In some localities therefore methods of "pillar" work appear to be indigenous; in others the practice has always been to remove the whole of the coal at one operation, or as it is commonly called to work it "longwall."

These two modes of working are illustrated in the sectional diagrams Figs. 1 and 2, Plate 42. The statical pressure of the overlying strata upon the seam of coal A A is equal in round numbers to 1 lb. per square inch for each vertical foot of depth. By the method of pillar work, Fig. 1, narrow portions B B are removed, and the weight previously supported by them is thrown upon the pillars left between. In the method of longwall work, Fig. 2, the object in view is to encourage the subsidence of the strata over the whole wrought area C, and thus reduce to a minimum the additional pressure thrown upon the solid seam at the face of the working D: and to this end the areas of extraction of the coal are made large, and the working face is kept in a straight line in order to facilitate the formation of lines of fracture in the superincumbent mass. Thus supposing a longwall face of say 500 yards length is advancing across the section D A, Fig. 2, in the direction of the arrow: as the coal is removed, the superincumbent weight is thrown upon the seam in advance of the working face, until it is sufficient either to bend down or fracture the rocks immediately behind the face so that they rest on the floor of the wrought mine. Practically a sagging or bending of the strata first takes place, and then a line of fracture is formed, as in Fig. 2; this resolves itself ultimately into a sort of wave or undulation of the strata higher up, which follows continually the advancing face. It is therefore evident that the longer and straighter are the advancing faces, the more promptly will this subsidence of the strata and consequent relief of the extra pressure on the unwrought coal ensue; and the principal point in longwall mining is to reduce to a minimum the additional pressure that is thrown upon the unwrought coal by the act of working. The absolute amount of this additional pressure, and consequently the difficulty of keeping the working places open, is but slightly affected by the vertical depth of the seam below the surface; for although the weight of the overlying rocks is thereby increased, the thickness to be fractured and therefore also the resistance to shearing are increased in the same ratio.

In the actual working of a longwall mine, the first operation is to drive headways in the solid coal; and when these have attained a sufficient length, working faces or stalls are started from the side of one of them, and the coal is removed in a series of slices parallel to the headway course. To support the roof of the working places, timber props are set, and pack walls of loose stone are built up at regular intervals. As the faces advance, the timber props are removed, and the roof settles down, often without fracture, upon the pack walls. The roadways for the conveyance of the coal are carried at intervals of 20, 30, or 40 yards between pairs of pack walls; and as the roof settles down and squeezes everything tight, the requisite height for the roadway is maintained by ripping or cutting up into the roof. The roadways therefore of a longwall coal mine are carried through the goaf or wrought area, and practically in the roof of the coal seam.

Haulage.—The application of power for the underground haulage of coal presents many interesting points for the consideration of engineers. No successful experiments have as yet been made in direct traction by a locomotive; the heat and smoke would not only vitiate the ventilation, but also introduce the risk of fire, and in most cases soften and break down the roof of the roadways. It seems improbable therefore that direct steam traction will ever be used, except in a case where there is an arched roadway, moderately level, and which can be provided with a distinct ventilation: a combination of circumstances that is not likely to occur often in practice. Attention may now be confined accordingly to stationary engines driving ropes or chains.

The simplest case of underground haulage is when a loaded train is drawn up an incline by a *single rope*, and the weight of the empty train is sufficient to take the rope out again. The method of hauling by *main and tail ropes* is a modification of the foregoing, designed to work roads which are either level or of mixed rising and falling gradients; and it consists simply in adding a second or tail drum to the single drum of the former method. The main drum hauls the load towards the shaft, and the tail drum draws the empty wagons back again by means of a tail rope, which is led away from the drum to the extreme end of the roadway, passes round an end turning pulley there, and is attached to the tail end of the train of wagons, the arrangement consisting virtually of two drums pulling at opposite ends of the same rope. A third method of haulage is by the *endless rope*, which is driven either by a clip pulley or by grooved wheels; the wagons are attached in trains to the rope by means of clip tongs, which grip the rope and enable it to draw the train. In all these methods the power is applied by means of a rope supported on carrying rollers which are fixed at intervals along the floor of the roadway, and the wagons are connected together in long trains, as shown in Fig. 3, Plate 42. A fourth method, which has an important superiority in economy of power, is shown in Fig. 4, and consists in using an *endless chain*, and running the wagons not in long trains, but singly, spaced one by one at intervals along the roadway, and carrying the chain, which rests upon them instead of running upon rollers.

It is not intended within the limits of the present paper to attempt a detailed analysis of the advantages and disadvantages of these different methods of hauling, but simply to call attention to what may be considered the mechanical aspects of the question. A roadway driven in a coal seam has rarely the chance of being both level and straight. Even in districts where the strata have one general direction of dip, there are minor undulations which would require that a roadway driven along a level line should take a somewhat circuitous course in order to follow the seam of coal; or if driven straight, in the mean direction of the level line, that it should have a rising and falling line of section. In arranging any general system of underground haulage it is necessary to carry main roadways not merely on a level course but to the rise or dip, or indeed in any direction which may be dictated by the position of the coal to be worked in reference to the winding shafts. Any method of hauling trains of wagons evidently obtains its most favourable circumstances when the roadway is at once level and straight, as the useless work to be done in both directions consists in overcoming the friction and bending resistances of the ropes on the rollers and turnwheels, and these resistances are least under those circumstances. If to keep a roadway level it is made more circuitous, the friction of the wagons remains approximately the same, but each additional bend increases the rope friction and wear and tear. If to avoid this increased rope friction the roadway is taken straight, with rising and falling gradients, the state of circumstances approaches that shown in the rough section, Fig. 3, Plate 42, representing a roadway of undulating gradient, on which the haulage is effected by main and tail ropes or endless rope. In ascending the bank E the engine has to overcome the gravity of the loaded train, the friction of the tubs, and the friction of the ropes and drums. In descending the slope G the gravity of the loaded train is probably sufficient to overcome its own friction, and to make it necessary to apply the break to the tail drum in order to prevent the train from over-running the engine. In the return of the empty train there is a reversal of the strains; the power of the engine must now be transmitted to the extreme end of the roadway and brought back to the tail end of the train, and the action of the load in traversing the ascending and descending gradients has much the same character as before. Practically upon a roadway of moderate length and with its extreme ends at the same level it is found necessary to expend nearly as much power in returning an empty train as in bringing out the loaded one.

In the case of the "endless-chain" haulage, shown in Fig. 4, Plate 42, the strains are of a different character; and the contrast between this method and the preceding will be clearly brought out by supposing the endless chain applied to effect the haulage over a roadway with the same ascending and descending gradients as in the previous case, Fig. 3. The chain being now carried by the wagons, Fig. 4, has no direct friction on the roadway, and increases the wagon friction by the mere addition of its weight. The wagons in fact serve as running rollers to the chain, and by their height prevent it from touching the ground. The loaded wagons descending the incline G transmit a hauling power minus their wheel friction to the wagons ascending the bank E. The same state of balance exists between the empty return wagons spaced uniformly along the road; and as the turnwheels at the ends of the roadway connect the two chains of wagons together, a complete equilibrium of load would be established if both were empty. This holds true whatever are the undulations of the roadway, and whether the ends of it are at the same level or not. Consequently the work to be done when one of the lines of wagons is loaded and the other empty is merely to overcome the gravity of the load and the wheel friction of both lines of wagons. The average coefficient of friction of pit wagons is about 1-50th of their weight; and it is found that if an endless-chain roadway has a mean fall with the load of 1 in 30, the gravity of the full wagons supplies sufficient hauling power to overcome the whole wheel friction and to take the empty wagons up.

In the practical working of this mode of hauling it is usual for the chain to lie on the top of the wagons, resting on their ends; and the chain drops loosely into a fork on one of the ends, for connecting the wagon. But in the collieries of this district, it is the practice to send out large blocks of coal, which rise considerably above the top of the wagon, and the loading of these is facilitated by leaving one end of the wagon open. On this account in the Hucknall Colliery, of which a general design is shown in Fig. 9, Plate 44, the chain is carried by a small hook H attached to the middle of the outer side of each wagon, Figs. 5 to 7, Plate 43; and the tendency of the wagons to twist on the rails is found to be insignificant, and is also checked by the tension of the chain which extends all along the side of each wagon. The chain of its own accord lifts itself off the hook as each wagon in succession approaches the end turning pulley, as seen in Fig. 6. The speed of the chain is slow, rarely exceeding 3 miles per hour, and the tubs are spaced at intervals of from 20 to 25 yards along it. In the colliery diagram, Fig. 9, M M represent the main roadways of the mine, along which as the workings extend the chain haulage is to be applied, as indicated by the dotted lines in the roadways; and J J represent short branch ways through which the coal is conveyed from the working faces to the chain roads.

Raising.—The application of steam power to the raising of coal is not one that is favourable to the realisation of a high percentage of useful effect from the gross power expended. Although it is possible to balance accurately the weight of the cages, tubs, and ropes used in winding, yet the large amount of power expended in bringing this great weight of machinery from a state of rest into rapid motion every time a load is drawn to the top is unavoidably lost. The general method of winding coal is by the alternate wrapping and unwrapping of a pair of ropes coiled in opposite directions on drums or rope-rolls driven by the engine, as shown in Fig. 15, Plate 46. As one rope is wound up, the other is unwound, and thus the cages attached to them are approximately balanced. In deep shafts however the weight of the ropes exceeds the net load, and it is usual to balance them either by a third special drum and counterbalance chain, as in Figs. 12 and 13, or by coiling them upon a double conical drum, as in Fig. 14, the angle of the cone being such that the moments of load with empty cages are at every position of the cages approximately the same. The actual working of a colliery winding engine consists of a rapid series of alternate motions in opposite directions. In raising a large tonnage of coal, each journey of the cages is effected in less than a minute, and in each journey it is necessary to put the machinery into motion and to bring it to rest within that space of time; and when cages are used having two or more decks or flats, these have all to be raised and lowered to their proper positions for loading or discharge.

For the purpose of elucidating some points of interest in connection with this class of machinery, experiments have been made by the writer with three engines of different descriptions, at work at collieries in the Midland coalfield, and each capable of raising coal at the rate of 100 tons per hour.

No. 1 is a 40-inch single-cylinder high-pressure vertical engine of 5 feet stroke, shown in Figs. 12 and 13, Plate 46, which is fitted with a pair of cylindrical flat-rope drums D D 12 feet diameter, and a small balance drum and chain B, the action of the balance chain being to assist the engine until the cages meet, and then to absorb power during the remainder of the run; a weight W of 24 cwts. is suspended at the bottom of the balance chain, which works in a small pit. This engine is at work at the Cinderhill Colliery near Nottingham. The depth of the shaft is 222 yards, and the weight of the rope is 16 lbs. per yard, giving 31¾ cwts. as the total weight of rope suspended in the shaft. Each cage weighs empty 25½ cwts., and contains three coal tubs weighing 5 cwts. each; and the weight of coals drawn in each lift is 33 cwts.

No. 2 is a horizontal high-pressure engine, shown in Fig. 14, with a pair of 36-inch cylinders and 6 feet stroke, fitted with a double conical round-rope drum D, the cone increasing from 20 feet to 30 feet diameter. This engine is at work at the Kiveton Park Colliery near Sheffield. The depth of the shaft is 406 yards, and the weight of the rope is 9 lbs. per yard, giving 32½ cwts. as the total weight of rope suspended in the shaft. Each cage weighs empty 20 cwts., and contains two tubs weighing 5½ cwts. each; and the weight of coals drawn in each lift is 22 cwts.

No. 3 is a horizontal high-pressure engine, shown in Fig. 15, with a pair of 36-inch cylinders and 6 feet stroke, fitted with a pair of cylindrical flat-rope drums D D 14 feet diameter, without counterbalance, the drums being constructed of wrought iron. This engine is at work at the Hucknall Colliery near Nottingham. The depth of the shaft is 413 yards, and the weight of the rope is 14½ lbs. per yard, giving 53½ cwts. as the total weight of rope suspended in the shaft. Each cage weighs empty 30 cwts., and contains four tubs weighing 6¼ cwts. each; and the weight of coals drawn in each lift is 45 cwts.

These cases afford therefore instances of a conical drum, and of balanced and unbalanced cylindrical drums. The accompanying Tables give the details of the experiments, as to gross and net moments of load, effective steam pressure and engine power, in each revolution of the engines; and the diagrams, Figs. 16, 17, and 18, Plate 47, show these moments of load and the power actually expended in raising one load or cage of coal. The horizontal lines in these diagrams represent the successive revolutions of the engine, the dotted line shows the moment of the load throughout its ascent, and the full line shows the corresponding moment of the power

TABLE I.

No. 1 Winding Engine. Single Cylinder, 40 ins. diam., 5 ft. stroke.

(Cinderhill Colliery.)

Moments of Load and Engine Power in each Revolution. (See Figs. 12 and 16, Plates 46 and 47.)

No. of Revolution.	Ascending Load.				Descending Load.				Net Load on Engine WITHOUT Balance Chain.	Balance Chain.				Net Load on Engine WITH Balance Chain.	Engine Power.	
	Weight of Cage, Tubs, and Coal.	Weight of Rope.	Distance travelled.	Moment of Load.	Weight of Cage and Tubs.	Weight of Rope.	Distance travelled.	Moment of Load.		Weight at bottom of Chain.	Weight of Chain.	Distance travelled.	Moment of Chain.		Effective Steam Pressure. Lbs. per sq. in.	Total Engine Power.
No.	Lbs.	Lbs.	Ft.	Ft-lbs.	Lbs.	Lbs.	Ft.	Ft-lbs.	Ft-lbs.	Lbs.	Lbs.	Ft.	Ft-lbs.	Ft-lbs.	Lbs.	Ft-lbs.
1	8232	3552	41·6	490,214	4536	257	48·1	230,543	259,671	2700	60	10·7	29,532	230,139	32·8	411,968
2	,,	3332	42·1	486,844	,,	513	47·6	240,332	246,512	,,	140	10·1	28,684	217,828	28·2	354,192
3	,,	3109	42·6	483,127	,,	766	47·1	249,724	233,403	,,	228	9·5	27,816	205,587	28·2	354,192
4	,,	2883	43·1	479,056	,,	1016	46·6	258,723	220,333	,,	324	8·9	26,914	193,419	26·9	337,864
5	,,	2654	43·6	474,630	,,	1263	46·1	267,334	207,296	,,	428	8·3	25,962	181,334	20·4	256,224
6	,,	2422	44·1	469,841	,,	1507	45·6	275,561	194,280	,,	540	7·7	24,948	169,332	20·4	256,224
7	,,	2187	44·6	464,687	,,	1748	45·1	283,408	181,279	,,	660	7·1	23,856	157,423	20·1	252,456
8	,,	1949	45·1	459,163	,,	1986	44·6	290,881	168,282	,,	...	6·8	...	168,282	20·1	252,456
9	,,	1708	45·6	453,264	,,	2221	44·1	297,984	155,280	,,	660	7·1	−23,856	179,136	20·1	252,456
10	,,	1464	46·1	446,986	,,	2453	43·6	304,720	142,266	,,	540	7·7	−24,948	167,214	17·1	214,776
11	,,	1217	46·6	440,323	,,	2682	43·1	311,096	129,227	,,	428	8·3	−25,962	155,189	17·1	214,776
12	,,	967	47·1	433,273	,,	2908	42·6	317,114	116,159	,,	324	8·9	−26,914	143,073	16·4	205,984
13	,,	714	47·6	425,830	,,	3131	42·1	322,781	103,049	,,	228	9·5	−27,816	130,865	−25·0	−314,000
14	,,	458	48·1	417,989	,,	3351	41·6	328,099	89,890	,,	140	10·1	−28,684	118,574	−24·3	−305,208
15*	,,	199	38·1	321,221	,,	3552	38·1	308,153	13,068	,,	60	10·7	−29,532	42,600	−10·0	− 94,200
Totals			666·0	6,746,448			666·0	4,286,453	2,459,995			131·4	...	2,459,995	Net	2,650,160

* The last turn is only about three quarters of a revolution, and the effective steam pressure is estimated at −10 lbs.

TABLE II.

No. 2 Winding Engine. Two Cylinders, 36 ins. diam., 6 ft. stroke.

(Kiveton Park Colliery.)

Moments of Load and Engine Power in each revolution. (*See Figs.* 14 *and* 17, *Plates* 46 *and* 47.)

No. of Revolution.	Ascending Load.				Descending Load.				Net Load on Engine.	Engine Power.	
	Weight of Cage, Tubs, and Coal.	Weight of Rope.	Distance travelled.	Moment of Load.	Weight of Cage and Tubs.	Weight of Rope.	Distance travelled.	Moment of Load.		Effective Steam Pressure. Lbs. per sq. in.	Total Engine Power.
No.	Lbs.	Lbs.	Ft.	Ft-lbs.	Lbs.	Lbs.	Ft.	Ft-lbs.	Ft-lbs.	Lbs.	Ft-lbs.
1	5936	3654	66·7	639,653	3472	282	94·2	353,627	286,026	41·6	1,016,371
2	,,	3454	70·6	662,934	,,	564	94·2	380,191	282,743	37·0	903,984
3	,,	3242	74·5	683,761	,,	846	94·2	406,756	277,005	33·0	806,256
4	,,	3018	78·4	701,994	,,	1128	94·2	433,320	268,674	33·0	806,256
5	,,	2782	82·3	717,491	,,	1410	94·2	459,884	257,607	33·0	806,256
6	,,	2534	86·2	730,114	,,	1692	94·2	486,449	243,665	29·1	710,971
7	,,	2274	90·1	739,721	,,	1974	94·2	513,013	226,708	29·1	710,971
8	,,	2002	94·2	747,760	,,	2246	90·1	515,192	232,568	29·1	710,971
9	,,	1720	94·2	721,195	,,	2506	86·2	515,304	205,891	28·4	693,869
10	,,	1438	94·2	694,631	,,	2754	82·3	512,400	182,231	−39·7	−969,950
11	,,	1156	94·2	668,066	,,	2990	78·4	506,621	161,445	−37·5	−916,200
12	,,	874	94·2	641,502	,,	3214	74·5	498,107	143,395	−33·0	−806,256
13	,,	592	94·2	614,938	,,	3426	70·6	486,999	127,939	−31·0	−757,392
14	,,	310	94·2	588,373	,,	3626	66·7	473,437	114,936	−17·9	−437,333
15*	,,	28	9·3	55,465	,,	3654	9·3	66,272	− 10,807	−10·0	− 30,510
Totals			1,217·5	9,607,598			1,217·5	6,607,572	3,000,026	Net	3,248,264

* The last turn is only about one eighth of a revolution, and the effective steam pressure is estimated at − 10 lbs.

TABLE III.

No. 3 Winding Engine. Two Cylinders, 36 ins. diam., 6 ft. stroke.
(Hucknall Colliery.)
Moments of Load and Engine Power in each revolution. (*See Figs.* 15 *and* 18, *Plates* 46 *and* 47.)

No. of Revolution.	Ascending Load.				Descending Load.				Net Load on Engine.	Engine Power.	
	Weight of Cage, Tubs, and Coal.	Weight of Rope.	Distance travelled.	Moment of Load.	Weight of Cage and Tubs.	Weight of Rope.	Distance travelled.	Moment of Load.		Effective Steam Pressure. Lbs. per sq. in.	Total Engine Power.
No.	Lbs.	Lbs.	Ft.	Ft-lbs.	Lbs.	Lbs.	Ft.	Ft-lbs.	Ft-lbs.	Lbs.	Ft-lbs.
1	11,200	6000	48·5	834,200	6160	287	57·3	369,413	464,787	32·0	781,824
2	,,	5767	48·9	829,686	,,	562	56·9	382,482	447,204	32·0	781,824
3	,,	5532	49·3	824,888	,,	835	56·5	395,217	429,671	32·0	781,824
4	,,	5295	49·7	819,801	,,	1106	56·1	407,623	412,178	28·3	691,426
5	,,	5056	50·1	814,426	,,	1375	55·7	419,699	394,727	28·3	691,426
6	,,	4815	50·5	808,757	,,	1642	55·3	431,451	377,306	28·3	691,426
7	,,	4572	50·9	802,795	,,	1907	54·9	442,878	359,917	28·3	691,426
8	,,	4327	51·3	796,535	,,	2170	54·5	453,985	342,550	24·7	603,470
9	,,	4080	51·7	789,976	,,	2431	54·1	464,773	325,203	24·7	603,470
10	,,	3831	52·1	783,115	,,	2690	53·7	475,245	307,870	24·7	603,470
11	,,	3580	52·5	775,950	,,	2947	53·3	485,403	290,547	21·8	532,618
12	,,	3327	52·9	768,478	,,	3202	52·9	495,250	273,228	21·8	532,618
13	,,	3072	53·3	760,698	,,	3455	52·5	504,787	255,911	21·8	532,618
14	,,	2815	53·7	752,605	,,	3706	52·1	514,019	238,586	21·8	532,618
15	,,	2556	54·1	744,200	,,	3955	51·7	522,945	221,255	19·9	486,197
16	,,	2295	54·5	735,477	,,	4202	51·3	531,571	203,906	19·9	486,197
17	,,	2032	54·9	726,437	,,	4447	50·9	539,896	186,541	15·4	376,253
18	,,	1767	55·3	717,075	,,	4690	50·5	547,925	169,150	5·8	141,706
19	,,	1500	55·7	707,390	,,	4931	50·1	555,659	151,731	– 6·4	–156,365
20	,,	1231	56·1	697,379	,,	5170	49·7	563,101	134,278	– 4·5	–109,944
21	,,	960	56·5	687,040	,,	5407	49·3	570,253	116,787	– 7·0	–171,024
22	,,	687	56·9	676,370	,,	5642	48·9	577,118	99,252	– 1·7	– 41,534
23	,,	412	57·3	665,368	,,	5875	48·5	583,697	81,671	– 7·6	–185,683
24*	,,	135	23·3	264,105	,,	6000	23·3	283,328	– 19,223	0·0	...
Totals			1,240·0	17,782,751			1,240·0	11,517,718	6,265,033	Net	9,877,861

* The last turn is only about half a revolution, and the effective steam pressure is estimated at zero.

exerted; the depth of shaft and the area representing the load are reduced to the same dimensions in each diagram, for the purpose of comparison of the engine power. The corresponding sets of indicator diagrams are given in Figs. 19 to 24, Plates 48 to 50.

The mode of working the engines in each case is as follows. In engine No. 1, shown in Figs. 12 and 13, the engineman works with the throttle-valve open, "hands" the engine by the handle H until fairly in motion, and then places the handle in a notch on one of the eccentric rods until the run is nearly completed, when he detaches the valve-motion, meets the piston with steam on the opposite side, as shown at A in the diagram Fig. 16, and so brings the engine to a stand. The starting, running, and stopping occupy 30 seconds. The foot break is rarely used.

In engine No. 2, shown in Fig. 14, the engineman also works with an open throttle-valve, and regulates the engine with the link motion. In starting the engine he puts the link-block at its extreme travel, moves it backward as the speed increases, and in the last five strokes reverses it so that the pistons pump steam back into the boiler, as shown at B in Fig. 17. The steam break is used in case of need.

In engine No. 3, shown in Fig. 15, the steam and exhaust valves are all driven through a link motion; the throttle-valve is a double-beat valve actuated by a worm. The engine is worked in full gear, steam being given at starting through the open throttle-valve: when the run is nearly completed the throttle-valve is nearly closed and a partial vacuum is consequently formed on the steam side of the piston, the engine still being in forward gear. The principal agent in bringing the machinery to rest in this case is the vacuum behind the piston, as shown at C in Fig. 18; and this explains the different character of the line of steam power in Fig. 18 as compared with the two other diagrams.

Direct economy of fuel consumption is not in itself a point of much importance in colliery engines, the supply of fuel being abundant and on the spot: it is rather a question of boiler room, and wear and tear of boilers. It is a matter of much importance however to have the machinery so constructed that the engines may develop a maximum of useful effect, and that they may do this with the least amount of strain upon the working parts. The most important point is the effect exercised by the weight of the machinery that is put into rapid motion and stopped in such short intervals of time. In the case of the engines Nos. 1, 2, and 3, the loads are drawn from the depths of 222, 406, and 413 yards in 30, 45, and 45 seconds of time respectively. The mean speed of the cages is therefore about 22, 27, and 27 feet per second; but as about one half of the revolutions are either accelerating or diminishing in velocity, the maximum speed of the cages is probably 27, 36, and 36 feet per second. The weights in motion in the three cases may be estimated at 27 tons in No. 1 engine, 60 tons in No. 2, and 30 tons in No. 3, these amounts being made up as follows:—

	No. 1 engine. Tons.	No. 2 engine. Tons.	No. 3 engine. Tons.
Flywheel and Drums	15	45	12
Ropes	4	4½	7
Cages, tubs, and coal	6	4	8
Pulleys	2	6½	3
Total weight in motion, tons . .	27	60	30

These different parts travel, some at a higher, some at a lower speed than the coal, the mean being probably about the same as the coal.

the mass in motion 60 tons; the result is therefore 2,721,600 foot-pounds exerted in 66 per cent. of $\frac{3}{4}$ minute, giving 166 effective horse power. In engine No. 3, the maximum velocity being also 36 feet per second, but the mass in motion 30 tons, there are 1,360,800 foot-pounds expended in 79 per cent. of $\frac{3}{4}$ minute, equal to 70 effective horse power. The power thus stored up in the moving parts is in the case of No. 2 engine expended during the last five strokes in forcing steam back into the boiler; in engine No. 3 it is taken up in moving the engine without steam and with a partial vacuum behind the pistons; and in No. 1 engine it is neutralised by the full boiler pressure opposing the motion of the pistons. Thus in all these cases the engine is employed usefully in raising the load during only about two thirds of its working time, and during the remaining one third it is exerting a retarding action; this is more especially the case with No. 2 engine having the conical drum, owing to the great weight of the drum that has to be stopped.

It is obvious that if the machinery were so designed that the work of the engine was constant during the whole of its journey, a smaller and therefore less expensive engine would be capable of performing the same amount of useful work, and would be free from the extra strain which is unavoidable when the engine is reversed under steam. It is therefore a question of some importance to determine the design of a machine which would accomplish this end. With a conical drum a perfect equilibrium of load can be obtained in every position of the cages; but it is seen from the diagrams of No. 2 engine, Figs. 17, 21, and 22, Plates 47 and 49, that the conical drum brings with it the disadvantage of a great increase in the weight of the moving parts. Much may indeed be done by so designing the machinery that a maximum of strength may be obtained with a minimum of weight; but the improvement must extend further in the direction of reducing the load on the engine at the commencement of the run and expending the momentum usefully at its termination in raising the load. The following may be suggested as one method of accomplishing this end. Suppose the full lines in Fig. 8, Plate 43, represent the contour of a conical drum in which there is perfect statical equilibrium between the ascending and descending loads throughout the entire run; and let it be assumed that by an economical method of construction the whole moving mass is kept within 40 tons moving at the maximum speed of 36 feet per second in the shafts. The point to be arrived at is so to modify the contour line of the drum, that in the first strokes of the engine its greatest available power shall be exerted in bringing the machinery into motion, that in the middle strokes it shall just lift the load and overcome the friction, and that in the last strokes the leverage of the load shall be so much increased that the momentum of the moving parts shall be usefully expended in assisting the engine to complete the lift. This end would be approximately obtained with a drum in which the contour lines received the modification indicated by the dotted lines in Fig. 8, simply increasing the steepness of the cone. With this drum the weight of the empty cage acting on the large radius at the commencement of the run would be in excess of the full cage and rope acting on the small radius, and the surplus or excess of balance over the load would assist the engine in getting up the momentum of the moving parts; whilst at the termination of the run, the circumstances being exactly reversed, there would with the proper angle of cone be an equal amount of load unbalanced to absorb usefully the momentum of the moving parts. By this means not only would to prevent them from retarding the air current in the shafts; and for this purpose each platform of the cage holds only one tub of coals, and is equal in area to 1-5th of the shaft. There are however four of these platforms or decks in each cage; and to save part of the time occupied in moving the cages for loading and emptying them, there are two levels for loading and discharge, both at top and bottom of the shaft, so that all the decks can be loaded and emptied with only one change in the position of the cages. The whole time occupied in loading and emptying is thus not more than 20 seconds in each journey, and the engine can raise from 180 to 200 wagons of coal per hour, each wagon containing from 9 to 15 cwts. of coal.

Mr. Fowler mentioned that the winding gear shown in Figs. 10, 11, and 15, and the winding engine No. 3, from which the diagrams Figs. 18, 23, and 24 were taken, would be seen in action by the members visiting Hucknall Colliery that afternoon.

The Chairman observed that in the diagrams representing the work of the engines (Figs. 16, 17, and 18), the power exerted appeared to be in excess of the load through fully two-thirds of the run, which would cause the speed of the engine to be continuously accelerated up to that point; and as the area representing the retarding power of the engine throughout the remainder of the stroke was seen in Figs. 16 and 17 to be so nearly equal to the previous accelerating power, it would appear that there must be very little friction in the shafts in those cases. In the third case however, Fig. 18, the area of the retarding power was so much smaller than that of the accelerating power, that the friction would seem to be considerably greater than with the two other engines; and he enquired whether the reason of this difference had been ascertained.

Mr. Fowler said he had not been able at present to account for the difference pointed out in the positive and negative areas of the diagram, Fig. 18; but he had no hesitation in attesting the general accuracy of these power diagrams, as they had been constructed from a series of indicator diagrams taken with a Richards indicator, from which those shown in Figs. 19 to 24 had been selected. In the case of No. 3 engine, the indicator diagrams shown in Fig. 23 were obtained in the first, eleventh, and sixteenth revolutions of the engine, during the period of acceleration; and the diagrams shown in Fig. 24, taken in the nineteenth and twenty-first revolutions, when the throttle-valve had been almost closed, showed a partial vacuum behind the pistons, amounting in the twenty-first revolution to 6 lbs. or 7 lbs. below the atmosphere. The indicator diagrams from No. 1 engine, shown in Fig. 19, were taken in the first, seventh, and twelfth revolutions, during which the accelerating power was continued; and the two lines taken in the thirteenth and fourteenth revolutions, Fig. 20, showed the retarding effect when the engineman had disconnected the valve-gear and worked the valves by hand, so as to make the full pressure of steam meet the piston in each stroke. In the case of No. 2 engine, the indicator diagrams were taken in the first, fourth, and ninth revolutions, as shown in Fig. 21, before the engine was reversed; and after reversing, the lines in Fig. 22 were taken in the eleventh and thirteenth revolutions, the pistons then pumping steam back into the boiler.

Railway, in the counter-pressure experiments of which the particulars had been given at the meeting of the Institution in January last (see Proceedings Inst. M. E. 1870 page 44). In those experiments the counter-pressure in the cylinders had amounted to as much as 150 lbs. while the boiler pressure was only 120 lbs., and the excess he considered to be due to the momentum of the steam in the steam pipe rushing into the empty space of the cylinder, and acting therefore as a steam ram in a manner somewhat analogous to a hydraulic ram. The expenditure of power by this winding engine, amounting to 166 horse power, was probably not so wasteful as it appeared in the paper to be considered, because in the counter-pressure working a large proportion of this power would be restored in the shape of increased steam pressure in the boiler, where it would thus be stored up ready to be utilised in the next run. In the case of small locomotive boilers in France he understood the rise of pressure in the boiler while running with the counter-pressure steam had been distinctly noticed.

Mr. W. Bouch enquired what arrangement had been made in No. 2 winding engine for ensuring that it should pump back steam instead of air into the boiler in the reversed working. If it were simply an instance of ordinary reversing and pumping air into the boiler, it was true that the resistance occasioned by the compression of the air would be effectual in destroying the momentum of the moving machinery; but he doubted whether the air so pumped into the boiler would occasion any such increase of boiler pressure as had been alluded to, because the much lower temperature of the air would produce a reduction in temperature of the steam and a consequent partial condensation; and unless the boiler contained a large proportion of steam space, he did not think much power could be stored up in it by pumping air into it in the reversed working, because it was found in locomotives, that whenever air was pumped into the boiler in running reversed, the limit of pressure was soon arrived at and the safety valves began to blow off, and the air speedily made its escape there, unless the boiler was very capacious. The excess of pressure in the cylinders above the boiler pressure, as shown by the indicator diagram of the reversed working, would be accounted for, he suggested, if the throttle-valve were at that time partly closed, which would interfere with the free passage from the cylinders back to the boiler and cause an increased pressure against the pistons.

Mr. Fowler explained that in the case of No. 2 winding engine the exhaust-pipe was of very large capacity, being 40 yards long and 10 inches inside diameter, and retaining therefore a large volume of steam at atmospheric pressure; and as the pumping back into the boiler in the reversed working was from the exhaust-pipe, the pistons drew in steam alone from it at first, and but little air got drawn into the cylinders during the four or five revolutions of the reversed working.

Mr. A. Paget concurred in the view which had been expressed, that if it were air which was pumped into the boiler in the reversed working, no advantage would be gained, because he considered the increase of pressure due to the volume of air pumped in would be far counterbalanced by the cooling effect of the air so supplied into the boiler.

Mr. Fowler said that the object of the diagrams representing the power exerted by the winding engines had not so much been to show that the portion representing the retardation was an actual loss of engine power, as in Figs. 16 and 17; but to call attention to the fact this cooling of the cylinder surfaces he thought must have been occasioned during the time that the engine had been reversed for the last third of the previous lift, at which time the cylinder had drawn in during the first half of each revolution a supply of exhaust steam of atmospheric pressure; and as this steam was very wet and on the point of condensation, it was capable he thought of robbing the cylinder surfaces of more heat than they could recover during the period of compression in the second half of each revolution from the then dry steam. The friction of the steam in the steam pipes, in conjunction with the obstructions offered to the passage of the steam by the steam-valve and partially closed throttle-valve, might be sufficient he thought to account for the whole excess of pressure in the cylinders above the boiler pressure; and in consequence of the elastic nature of steam he could not agree in thinking it possible that it should act as a steam ram in a manner similar to a hydraulic ram, as the weight of the steam was too insignificant to make up any appreciable momentum. Owing to the great length of the exhaust-pipe he thought there could be no doubt that in the reversed working the pistons would draw in steam chiefly.

Mr. F. J. Bramwell remarked that the total amount of obstruction presented to the passage of the steam by the steam-valve and throttle-valve was shown by the diagrams taken from the engine when working in forward gear, before reversing; from which it appeared that with a boiler pressure of 50 lbs. the pressure obtained in the cylinders was 46 lbs., showing a loss of 4 lbs. pressure in the passage of the steam from the boiler to the cylinders. In the reversed working the engine did not run more quickly, and the same difference of 4 lbs. pressure would therefore be enough to overcome the resistance of the valves and steam passages; but the actual excess of pressure observed in the cylinders above the boiler pressure, instead of being only 4 lbs., amounted to as much as 12 lbs., which was therefore much more than could be accounted for by the resistance of the valves and steam passages. The elasticity of steam did not appear to him to render it incapable of acting to some extent as a ram when its motion was suddenly checked: it must be remembered that steam, although a very light body, was still ponderable, and that the velocity with which it moved was very great, and thus there would be in the reversed working a large amount of momentum stored up in the steam rushing into the cylinder; and on its sudden stoppage this momentum was expended in compressing the elastic substance of the steam itself, and thus increasing its pressure to the extent shown by the indicator diagrams.

Mr. JEREMIAH HEAD observed that in the reversed working of No. 2 winding engine the exhaust steam was drawn into the cylinder at atmospheric pressure and therefore at the temperature of about 212° Fahr., and was then compressed say up to the boiler pressure of 50 lbs., at which its temperature would be about 300°; and in the next stroke the succeeding supply of exhaust steam drawn in would come into contact at once with the heated cylinder surfaces which had immediately before been in contact with the compressed steam at 300°. He did not see therefore how the atmospheric steam drawn into the cylinder could be deprived of any of its heat at the beginning of the stroke by contact with the cylinder surfaces; but on the contrary it would at that time receive heat from the hotter surfaces of the cylinder, and would afterwards restore this heat to them again in the latter part of the stroke, when itself heated by the compression.

Mr. G. D. HUGHES enquired what was the arrangement for working the valves in No. 1 winding engine, as it appeared from the indicator diagrams in Fig. 19, taken in the first, seventh, and twelfth revolutions of the engine, that the steam valve was much too late in closing, the full steam being kept on throughout the entire length of the stroke, without expansion; and also the eduction port was apparently opened much too late, producing the very large amount of back pressure shown in the diagrams, which must result in the loss of a large proportion of the effective power that the steam was capable of developing.

Mr. FOWLER replied that the steam and exhaust valves of all the three winding engines were double-beat valves lifted from eccentrics by rocking shafts and lifting fingers, and the diagrams shown in Fig. 19 were certainly very defective in the late closing of the steam valve and in the heavy back pressure.

Mr. W. Howe observed that the diagrams exhibited, representing the power exerted by the winding engines from bottom to top of the lift, were fair illustrations of the sort of diagrams ordinarily obtained from colliery winding engines; and the economical employment of the power in such cases was of much less importance than to have power sufficient for raising with rapidity and regularity great quantities of coal. At the Clay Cross Colliery he had two double-cylinder winding engines, with cylinders of 30 inches diameter and 5 feet stroke, fitted with balanced slide-valves, and both working under exactly similar circumstances, except that in one the lap of the slide-valve was 1 inch, while in the other it was only ½ inch. The latter was of course not quite so economical in working as the engine with 1 inch lap, but the ½ inch lap was found much better for starting the engine at the beginning of each lift; in this instance the coals had to be raised at the rate of 100 tons an hour by each pair of engines, and it was therefore a great advantage to be able to start the engines at a good speed, and the steam was kept on till nearly the termination of the lift, when the engines were stopped by reversing, generally without requiring the break to be used. At the same colliery the endless chain for underground haulage was now being put down on an extended scale, and it had the great advantage that it was kept constantly in motion, so that the power required to be exerted by the hauling engine was nearly uniform. Another advantage was that the endless chain could be readily applied in any place, and gave the means of drawing the coal at any angle and from any part of the pit with comparative ease. It brought the wagons along one at a time to the bottom of the shaft, as rapidly as they were filled in the workings, and the winding engine was thus kept regularly supplied, without having to stand waiting occasionally; whereas in bringing out trains of wagons with the tail-rope system the bottom of the shaft was sometimes glutted with wagons, while at other times the winding engine was standing idle. The wear and tear of the endless chain supported on the wagons themselves was also much less than that of the tail rope running upon carrying rollers fixed on the ground; and the use of the endless chain saved many of the horses previously required.

Mr. P. O. **Whitehead** mentioned that the endless-chain system was carried out for winding the coal up the shaft at the Marsden Pit near Burnley in Lancashire. The chain was provided at regular intervals with shackles, by which the loaded tubs were hooked on at the bottom of the shaft by hand; and on arriving at the top they were unhooked again by hand and landed at one side of the shaft, while the empty tubs were hooked on the descending chain at the other side. This plan of winding had now been in use there about ten years, the depth of the shaft being 112 yards.

Mr. J. S. E. **Swindell** concurred in thinking a considerable amount of lap was not desirable for the slide-valves of colliery winding engines. What was wanted was to get the coals away as rapidly as possible from the bottom of the shaft; and for this purpose the winding engine should have but little lap of the slide-valve, so as to start promptly with the load. When the valve had much lap, the engine was sometimes not able to start at once under the load, and it had then to be backed and started again with something of a run, thereby increasing the wear and tear. With less lap the load could be started straight away; and the economy of fuel attending a greater amount of lap was not a matter of much consequence in the case of engines at collieries.

The **Chairman** considered the paper which had been read was of much value, giving as it did authentic particulars of colliery working in that district; and it had also led to a discussion of much interest. He proposed a vote of thanks to Mr. Fowler for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon Excursions were made by the Members in three parties to High Park, Moor Green, Cinder Hill, and Hucknall Collieries, and Newstead Abbey; and the Members received a hospitable entertainment from the Colliery Companies at Basford Hall, and from Mr. Samuel Thomas Cooper at Bulwell Hall.

The Adjourned Meeting of the Members was held in the Great Hall of the Mechanics' Institution, Nottingham, on Wednesday, 3rd August, 1870; THOMAS HAWKSLEY, Esq., Vice-President, in the Chair.

The adjourned discussion was resumed upon the paper read at the previous meeting in April, "On a Steam Road Roller," by Mr. W. F. Batho of Birmingham and Mr. T. Aveling of Rochester. (See Proceedings Inst. M. E. April 1870 page 109.)

ON A STEAM ROAD ROLLER.

BY MR. W. F. BATHO, OF BIRMINGHAM, AND MR. T. AVELING, OF ROCHESTER.

(Adjourned Discussion.)

Mr. AVELING observed that the broken granite or other broken stone, employed for the repair of macadamised roads, was, at the time of laying it down upon the road, in a very fit state for making a level surface, as the newly broken pieces of stone had flat faces, with sharp angles that would enable the stones to bed properly with one another if well rolled at the time of laying down. But in the present practice of laying down stones without rolling, the edges were speedily worn off by the traffic, and the stones assumed the smooth rounded shape of the specimens exhibited, which he had picked up from a newly macadamised unrolled road in London after only a week's work under the regular traffic. In this state the stones were in the worst possible condition for making a good solid road surface; a little dry weather would cause them to work loose, and there was then the danger of horses being thrown down by them; and such a road was almost as objectionable as a street paved with round paving stones would be. Before a new layer of stones upon an unrolled macadamised road became really consolidated in their places, it was found that they were worn down by the traffic to only about two thirds of their original size; and considering that the granite employed for the repair of macadamised roads in London cost from 12*s.* to 14*s.* per cubic yard when broken ready for use, the loss arising from want of rolling must evidently be very serious, and it was most desirable that this mode of making roads should be superseded as soon as possible.

The size of the broken stones laid down upon macadamised roads rolled by steam power should not be larger he considered than those used for the unrolled roads; and this was also he believed the general opinion of the surveyors of roads. If large stones were used at all it should be only for the foundation of a road; and for a thickness of 1 inch or $1\frac{1}{2}$ inch at the surface the size should not exceed what would pass through a ring of $1\frac{1}{4}$ inch diameter, which was the practice on the roads in the best parts of London. Stones of this size made a better surface, settled down more quickly, and required less binding material to bed them than when not broken so small. In rolling a newly laid road by the steam roller, the first thing done was to pass the roller once over, so as to level the material and bring the flat faces of the stones uppermost; and then the sand forming the binding material was spread over and well watered. It was hardly possible to give any statement as to the quantity of sand and water to be employed, as this varied so much under different circumstances; but the less the better for the durability of the road, although enough must be used to bind or "grout" the stones thoroughly by filling up all the interstices between them, the sand and water being as necessary for consolidating the stones on a road as lime and water were for building purposes. The rolling was commenced at the sides of the road, and was gradually extended inwards towards the centre; and by the passage of the roller over the stones a good deal of the sand and water was worked up to the surface again, and was then swept by hand towards the centre of the road.

On account of the surface of a road in cross section being a convex curve, he thought in rolling it with a steam roller it was a mistake to have a cylindrical roller extending the entire width of the machine, as this would be likely to have the effect of forcing the road material upon the footpath on each side of the road. The same objection applied also to making the two side driving rollers truly cylindrical in the three-roller machine described in the paper, because the effect of wear would be to round off their inner edges, in the same way that all carriage wheel tyres were found to wear out from the inside of the wheel, in consequence of having to run on a slightly curved surface. In the first machine that he had constructed, the two driving rollers of 5 feet diameter had indeed been made of equal diameter on their inner and outer edges; but after a year's work they were found to be worn down to about an inch less in diameter on the inner edge than on the outer, and if continued at work would soon have worn so thin as to break on the inner side, before the outer side was nearly worn out. In the subsequent machines therefore the rollers had been made more nearly of the shape to which they would wear, so that the edge of the tyres should not become more worn than the body. The proper amount of cone for the tyres would of course depend upon the convexity of the road surfaces to be rolled; but as this varied greatly in different districts, he had adopted $\frac{3}{4}$ inch smaller diameter for the inner edge than the outer edge of the two driving rollers of 20 inches width in machines of 6 feet total width over the rollers, as shown in the drawing, Plate 51; and he had found that the tyres then wore regularly throughout the width of each roller.

The addition of bearing springs to the steam roller, with a view to obviating the risk of drains and pipes below the road surface being crushed in by the concussions in the passage of a heavy roller without springs, did not seem to him likely to prove effectual for the purpose contemplated; because the only portion of the weight that would be affected by the springs was the boiler and the other parts carried upon them. In a machine of 15 tons weight however, the rollers constituted much the largest part of the weight, amounting together to as much as 11 tons, which would not be affected by the addition of bearing springs. If the action of the springs were really desirable for a road rolling machine, it ought to be carried out for the rollers themselves by providing them with an elastic bearing upon the road, as was done in the road traction engines that were made with india-rubber tyres to the wheels; but such a machine would not be found efficient at all for rolling the roads. With regard to the greater speed at which it was considered the roller might travel when fitted with bearing springs, it did not appear to him desirable for the steam roller to travel faster than an ordinary horse roller; his own experience had been that 2 or $2\frac{1}{2}$ miles an hour was quite as high a speed as was necessary, and that with a machine of 15 tons weight the rollers and the stones were both damaged by travelling at a higher speed.

The instance of a truck loaded with pig iron passing noiselessly over a paved street in consequence of being provided with springs, as had been mentioned in the discussion at the previous meeting, did not appear to him to present an analogy applicable to the road roller, because the load carried upon the springs of the truck was in that case the chief part of the entire weight; whereas in the steam roller the greatest portion of the weight would necessarily be below the bearing springs.

The adoption of two steam cylinders for the roller was a step which his own experience with single-cylinder engines had led him to consider unnecessary, and with the single cylinder and link motion he had found there was practically no danger of the engine stopping on the centres. He had indeed purposely tried to stop it on the centre, but had never succeeded in doing so, the chief reason being that the motion was geared down to so great an extent, the crank shaft making 16 turns for one turn of the driving rollers; there was also a considerable amount of slack in the driving chain, which allowed the crank shaft to get a fair start in either direction before the pull came upon it. With a single steam cylinder, even up to 12 inches diameter, he considered the addition of a bedplate to carry it was unnecessary, the boiler itself forming a sufficient bedplate for the purpose. The plan of having a separate axle for each of the two driving rollers appeared to him undesirable on account of diminishing the simplicity of the machine and adding to its cost, which would stand in the way of its adoption by the road authorities; and where the machines had to be worked under the care of inferior engine-drivers and away from any repairing shops, it was indispensable for success that their construction should be as simple as possible, so that it might be impracticable for the machine to be put out of repair through carelessness. The increased width of road that could be rolled in each course by the machine, which had been referred to as an advantage that was obtained by the use of the two separate driving axles, was not greater than had previously been arrived at with a single driving axle; the steam roller at Liverpool, which was the second that he had made, was 9 feet wide over the rollers and weighed 30 tons, and continued working quite satisfactorily at the present time, having a single driving axle and a single steam cylinder; and he thought therefore no advantage was gained by the greater complication attending two separate driving axles. With the single driving axle the machine was still enabled to adapt itself to the varying shape of the road, by means of the swivelling turntable that carried the centre steering roller; this turntable not only allowed of steering the machine very easily, but being constructed with only two vertical carrying wheels for the turntable (J J, Figs. 2 and 4, Plates 19 and 21), placed longitudinally fore and aft, it was capable of swivelling vertically to the extent of 3 or 4 inches on either side; and consequently any one of the rollers in the machine, on passing over a hollow or a soft place in the road, could sink and compress the road surface as effectually at that spot as elsewhere, leaving the road rolled solid all over where the machine had been. For the effective action of a road roller however, it was desirable that each of the individual rollers composing it should not be made of too great a width, otherwise the outer and inner edges might ride on the hard part of the road, and there might be a soft part left under the middle not thoroughly compressed. He had found that rollers of 18 to 20 inches width and 5 feet diameter, as shown in Plate 51, proved the most effective of the various sizes that had been made; and he had now made altogether twenty-one of these single-cylinder machines, which were at work in different parts of this country and abroad.

Mr. F. A. Paget thought that one of the main advantages attending the rolling of roads by steam power consisted in the diminished proportion of mud or soluble matter that was then incorporated in the structure of the road surface. If the surface of an ordinary road that had not been rolled was broken up and the material washed, it was found that as much as half of it was soluble matter—mud, dirt, and very fine sand; the stones having only been thrown loosely upon the road had lain so long before becoming consolidated by the traffic, and had undergone in the meantime such extensive abrasion, that the proportion of mud, dirt, and pulverised material in the metalling was increased to that great extent, and the stones were really only stuck together by the mud. This accounted for the fact that, although an unrolled macadamised road might indeed after long use have a surface that was pretty good and hard in dry weather, and might offer then a very slight resistance to traction, yet it would quickly become soft and muddy when there was any rain. By the employment however of a steam roller upon the newly laid metalling of a macadamised road the stones were rolled in and well bedded at once, and the surface was thus consolidated into a sort of stone-felt, capable of resisting most effectually the action of the ordinary traffic, and containing the smallest quantity of soluble material to form mud in wet weather.

The CHAIRMAN enquired what had been the continued experience in the working of the steam road rollers employed in Paris.

Mr. H. CHAPMAN replied that the steam road rollers in Paris, of which a description had been given at a former meeting (see Proceedings Inst. M. E. 1869 page 101), continued in regular use there, and it had been found from the experience of their working that it was better to use a light roller first, running at a comparatively high speed, so as to shake the newly laid metalling into its place without crushing the stones; and afterwards a heavier roller was used for consolidating the road surface. The success of these rollers however had not yet been such as to lead to their adoption anywhere else in France, and he did not know of any other steam road rollers being used in France besides those employed in Paris.

The CHAIRMAN remarked that, according to the experience in Paris, it would be necessary for a town to have two rollers, a light one and a heavy one: and he enquired whether the use of the light roller was considered indispensable. He asked also whether the Paris rollers were owned by contractors or by the municipality.

Mr. H. CHAPMAN replied that the authorities in Paris insisted upon the light rollers being used first, for the purpose of shaking the metalling into its place by running over it at a comparatively high speed. The rolling was done by contract by the makers of the rollers, and was paid for at a stated rate per ton of roller per mile, so that a roller of 15 tons weight earned half as much per mile as one weighing 30 tons.

The CHAIRMAN enquired what gradient the Paris rollers would ascend.

Mr. H. CHAPMAN replied that they would ascend any ordinary incline, and the steepest inclination met with in Paris was about 1 in 10, which the rollers would ascend when the surface of the road was finished; but they could not go up an inclination of that amount upon newly laid metalling.

Mr. AVELING said that he had succeeded in rolling a road as steep as 1 in 10 with 6 inches thickness of newly laid metalling, but had accomplished this by going round by another road to the top of the hill so as to roll down hill the first time; and when the roller had once been down the hill, it had so far consolidated the metalling that it could go up hill again over the part already rolled. He had very recently witnessed the working of the rollers in Paris, and had seen one of the 15 ton rollers execute the rolling of the Rue Tronchet, which was all done at night, half the length of the street being finished in one night and the remainder on the following night. For general purposes he was informed by the road makers that they preferred the 15 ton roller, because it did not crush the material. The metalling used in Paris was inferior to the granite employed in London, and he had noticed that pieces were broken off by the passage of the 30 ton roller. His own experience of road rolling had been to the same effect, that it was better to roll roads a greater number of times with the lighter rollers of not more than about 15 tons weight, as a heavier roller destroyed some of the material, which was an expensive process.

The CHAIRMAN enquired whether many cases had occurred of gas and water pipes being injured by the passage of the steam rollers.

Mr. AVELING replied that there had not been any instances of breakage of gas or water pipes by the steam rollers in this country, excepting one case at Liverpool, where the 30 ton roller was employed, and one at Sheffield where the pipes had been laid within only 9 inches of the surface. If however the pipes were laid not less than 18 inches below the surface, he thought no danger need be feared from the use of steam rollers, and it would be more prudent in all cases to put pipes and drains at that depth or deeper. The actual pressure upon the ground per lineal foot width was only $2\frac{1}{2}$ tons in a 15 ton roller of 6 feet width, or less than $\frac{1}{4}$ ton per inch; and there were many vehicles passing over the pipes laid under a road which were of very much greater weight per inch width of their wheels.

Mr. E. LEIGH remarked that the plan which had been mentioned of making the tyres of the rollers smaller in diameter on their inner than on their outer edges would have the effect of introducing two speeds at the circumference of the rollers, producing a grinding action upon the road and a consequent loss of power; and he suggested that this might be obviated by having a separate axle for each roller, and merely giving the rollers a slight inclination to the extent required, keeping the diameter the same throughout the entire width of the roller. He enquired whether this plan would not be found preferable, in practice, by avoiding the friction and loss of power attending any conical form of roller.

Mr. AVELING replied that truly cylindrical rollers would of course be correct for a perfectly level road, and the suggested inclination of their axles would also be right for a thoroughly solid road having a uniformly curved cross section. But such roads were never met with in practice, the usual shape of the cross section being one which presented the greatest curvature at each side, while the centre of the road was nearly level, so that no rollers would bite over the whole extent of their bearing surface in all parts of the road; even when the rolling of a road had been finished and all the stones were bedded, the surface did not become thoroughly firm and concreted for three or four days, and consequently rollers arranged for some particular curvature of road would fail of realising the intended advantage. Having found by the actual working of the rollers that those made of equal diameter on their inner and outer edges became worn down most on their inner edge, in the manner already described, and afterwards did not alter their shape further, he had come to the conclusion that the best course was to make them of that shape in the first instance, by reducing the inner edge of each roller to a somewhat smaller diameter than the outer.

The CHAIRMAM moved a vote of thanks to Mr. Aveling, which was passed, for the useful information that he had given respecting the construction and working of the steam road rollers.

The following paper was then read:—

ON THE
CONCLUSIONS DERIVED FROM THE EXPERIENCE OF RECENT STEAM BOILER EXPLOSIONS.

BY MR. EDWARD B. MARTEN, OF STOURBRIDGE.

The records of Steam Boiler Explosions in recent years are very numerous, as the increased attention drawn to the subject in this and other countries has placed far more information at disposal; and the experience of the last four years, since a former paper was read by the writer on the subject of boiler explosions, has confirmed the opinion then expressed, that all boilers, however good in original construction, are liable in the course of time to get into bad order and explode. The particulars of the explosions during this period are given in the Tables appended to the present paper, which show the number of explosions due to each cause in each class of boiler, distinguishing those of the United Kingdom from those in foreign countries. An analysis is also given of the explosions in the last four years, showing the causes of explosion of each form of boiler; and also a summary of the causes of explosion under the three general heads of—(1) faults in construction or repair: (2) faults in working which creep on insidiously and unnoticed: (3) faults which might be seen and guarded against by careful attendants. Nearly all of the faults in these three classes would have been detected by periodical examination.

In the case of Cornish, Lancashire, and other boilers with internal flues, the faults of construction which have caused explosions have been weakness in the tubes, combustion chambers, ends, domes, or manholes; and explosions in these, as in other classes of boilers, have also resulted from external or internal corrosion, shortness of water, undue pressure of steam, and scale or mud on the boiler plates.

In plain cylindrical boilers, and others without internal flues, explosions have resulted from the boiler ends being made flat, and also from frequent repairs producing seam rips, especially in boilers having the plates arranged lengthways instead of in rings.

In marine boilers, weak flues and weak ends have also led to explosion, in addition to the other causes mentioned above.

Locomotive boilers have in two cases exploded in consequence of the strains thrown upon them by their being used as a frame for the engine.

Other explosions have resulted from want of stays, and from too much heat impinging on some particular part; and in domestic boilers from freezing of pipes under pressure.

Altogether the total number of explosions in this country that have been recorded during the past four years has amounted to 219, which may be classed under the following heads:—

Faults of construction or repair	95
Faults to be detected only by periodical examination	62
Faults which should be prevented by careful attendants	54
Extraneous or uncertain causes	8
Total	219

The causes of these 219 explosions may also be classed as follows:—

Worn out, corroded, or burnt plates	89
Undue pressure, overloaded valves, intentional or from carelessness	25
Bad construction, defective fittings or stays, or want of repair	69
Shortness of water, formation of scale or mud, or external flues set too high	28
Extraneous or uncertain causes	8
Total	219

Sketches of the most instructive examples of boiler explosions during the last four years are shown in the accompanying diagrams, Plates 52 to 61, which are sufficient to explain themselves, with a brief reference to their special features.

Although the importance of periodical examination as the best safeguard against explosion is generally admitted, a great number of those who make or use boilers have not at present sufficient belief in its importance to adopt this course. Boilers are still constructed or set in such a manner as to render examination next to impossible; and are continued to be worked without making it the duty of those who mind them, or of any one else, to examine every part at frequent intervals; and hence such explosions have occurred as shown in Fig. 1, Plate 52, in which the original position of the boiler before explosion is indicated by the dotted lines. It is thought by many steam users that all has been done which is possible, if their boilers are the best that can be procured, and are set in the most approved way; and it is taken for granted that such boilers should last for many years, under the idea that a good boiler can never explode unless the feed is neglected. Similar boilers are often referred to as having worked safely for ten or twenty years, but it is forgotten that they may be exposed to the insidious action of furrowing on the inside or channelling on the outside, such as caused the explosions of the originally good boilers shown in Figs. 2, 3, 4, and 5, Plate 52.

Much mischief arises from special classes of boilers, fittings, or apparatus, being looked upon as promising permanent safety from explosion; while the inevitable circumstance is overlooked that it is only so long as everything is maintained in good condition that safety is ensured. An apparatus, for instance, for preventing explosion from shortness of water or over-pressure, however perfect for any such object, would be quite inefficient as a safeguard against explosion from corrosion, furrowing, channelling, or weak construction. It is curious to note how often it is the case that every other part of an establishment is subject to severe and perpetual scrutiny, the engines especially being overhauled with the most scrupulous regularity; while the boilers, the very source of the power and the heart of the whole business, are left to themselves for long periods, even for years, without examination; and it is too often only after bitter experience that owners have understood the need of this examination. In this, as in many other matters, experience has shown that there is no royal road to safety, and that immunity is only secured by unremitting care and constant watchfulness. It should never be forgotten that even a good boiler can explode; for however good at the outset, sooner or later the time must eventually arrive, when such wear and tear will have taken place as will result in dangerous weakness, unless the boiler is carefully and systematically attended to. Although a boiler may even last safely for ten to thirty or more years if worked slowly and with care, no confidence can be placed in a boiler which has worked so long, unless it is examined in every part.

The opinion is more general than many are aware of, that explosions as a rule are caused by shortness of water and the sudden turning on of the feed water upon red-hot plates; and the appearances of injury in the plates from fire, arising in the ordinary course of working, have been frequently mistaken for signs of overheating from shortness of water at the time of explosion, as illustrated in Figs. 6 and 7, Plate 53. Although boilers do explode from the softening of the plates by overheating in consequence of shortness of water, yet it is very doubtful whether the turning on of the cold water at such a time is ever the cause of explosion. The feed water being always introduced at the bottom of the boiler, as in Figs. 8, 9, and 10, Plate 53, cannot be scattered suddenly near the overheated parts, but must rise gradually up the sides; and the boiler would have gone to pieces from the giving way of the softened parts long before the water reached them, as was the case in the explosions shown in Figs. 11 and 12, Plate 54. The experiment of injecting cold water into red-hot boilers has been carefully tried more than once, without producing any explosion.

Although it may be too much to suppose that boiler explosions will ever be entirely prevented, it is important that those who have the care of boilers should understand better what are the true causes of explosion, in order that they may know what to guard against in addition to shortness of water. This better understanding of the subject has been much retarded by the supposition that the causes of boiler explosions are beyond the comprehension of the boiler minders; and still more by the important differences of opinion among those under whom they work. Much evil has resulted from the promulgation of strongly expressed views, which have been founded upon facts but of too limited extent, and such as must become modified by consideration of the facts of a large number and variety of explosions. Mysterious theories to account for explosions have been resorted to only from want of clearer explanations.

Before considering in detail the causes of explosion, it is necessary to recall to mind that beyond question there is sufficient accumulated force in any working boiler to cause all the violent effects of an explosion, if this force be suddenly liberated. In Figs. 13 and 14, Plate 54, are shown the violent effects of the rupture of vessels employed for steaming rags, which were filled with steam only. In ordinary boilers however there is present, besides the steam, a quantity of water heated much beyond the atmospheric boiling point; and when rupture takes place and the pressure is suddenly relieved, part of this water evaporates, and keeps up the supply of steam to continue the rupture and destruction. The explosion of a boiler differs from the discharge of electricity or lightning, which cleaves the air and instantly leaves a vacuum; it also differs from the discharge of detonating compounds which act suddenly and leave a vacuum; but it more nearly resembles the discharge of gunpowder, which burns sufficiently slowly to keep up a continuous pressure behind a projectile until it leaves a gun; and each cubic foot of water in a boiler working at 60 lbs. pressure has been shown to produce in steam an explosive effect equal to one pound of gunpowder. None of the elaborate but unlikely theories of decomposed steam, or of electric accumulations, suppose a force so fitted to cause destruction as that contained in the highly heated water existing in all working boilers.

The following appear to be the general results to be derived from the experience of the explosions in this country during the last four years.

First as to faults of construction which fall under the department of the boiler maker or repairer. One of the most apparent causes of explosion in stationary boilers is the loss of strength occasioned by frequent repair, not only from the injury done to the old plates by removing rivets, but from the want of bond in the new work. This has led to many of the explosions of the Plain Cylindrical boilers, such as are shown in Figs. 15, 16, and 17, Plates 54 and 55. Where the plates are arranged longitudinally instead of in rings, the danger is increased, as there is less chance of a dangerous rip being arrested by a crossed joint. So great a number of boilers with continuous longitudinal seams, especially in the North, have worked for twenty or thirty years, that it can hardly be supposed they are any weaker than the boilers made in rings; but they are more liable to explode, for if a seam rip occurs, it more easily extends along the seam, and leads to the general break up of the boiler, as shown in Fig. 18, Plate 55.

Perhaps no boilers have worked for a greater number of years than the Plain Cylindrical boilers, many specimens being in existence and apparently in good order which were put to work fifty or sixty years ago. When such boilers have been too much or injudiciously repaired, they are treacherous and uncertain; but their rupture and explosion occur not so much on account of fault of shape, as from the simple reason that like willing horses they are easily overworked. The grates are usually twice as large as the fair proportion to the heating surface, producing the double evil of forcing more heat through the iron plates over the fire than they can transmit without injury, and allowing a great amount of heat to pass away to the chimney without useful effect. Careful experiment shows that nearly as good duty can be obtained with the plain cylindrical boiler as with any other form, provided the rate of combustion is in fair proportion to the extent of heating surface in the boiler. The circumstance that many plain cylindrical boilers have exploded is not sufficient to condemn this make of boiler, which is the cheapest, simplest, and most easily set. If the number of explosions alone were to be taken as the guide, it would lead to the condemnation of the Cornish and Lancashire boilers, from the experience of the past four years. But in the case of both plain cylindrical and other forms of boilers, most of the dangers admit of remedy, and can be guarded against by frequent examination.

Five very fatal explosions have occurred of boilers heated by Puddling and Mill Furnaces, leading in some cases to the supposition that this form of boiler is more liable to explosion than others. They were not adopted however in the iron-making districts without great care and consideration, and there does not seem ground for attributing special danger to them. The causes of the five explosions referred to of these boilers were manifest, and would have led to the explosion of any form of boiler; the loss of life however was great, because the situation of the boilers was among a large number of workmen. The steam power required in ironworks so far exceeds that in any other trade that an ironwork is half composed of boilers; the workmen are necessarily within the range of explosion of many boilers, and hence the great loss of life when such an accident occurs. The explosions of such boilers shown in Figs. 19 and 20, Plate 55, were from external and internal corrosion respectively of the bottoms, rendering them too weak to bear the ordinary pressure. Those shown in Figs. 21 and 22, Plate 56, were from the collapse of the central tubes, which were weakened by external and internal corrosion respectively. In Fig. 24, Plate 57, the shell was in bad order from over work and receiving too much heat from four large furnaces, one of these especially causing a constant mass of flame to impinge upon a single plate, which resulted in a seam rip.

The greatest number of explosions and the greatest loss of life and personal injury have been in the case of Cornish and Lancashire boilers or others with internal flues. In the county of Cornwall itself there have been many explosions, as often from the rupture of the shell, Fig. 23, Plate 56, as from the collapse of the tube, Fig. 25, Plate 57. The temporary patching on some of these old boilers was most extensive, Fig. 26, and the only wonder really was that they held together as long as they did. The belief that shortness of water is the only cause which can lead to the collapse of tubes is so strong, that the boiler minders have often been condemned almost unheard in cases of explosion, as if there were no room for doubt that their neglect was the cause. Explosions from weakness of tubes are not however confined to Cornwall, as for example in Fig. 27, where the flue was oval and very weak: although it was supposed that shortness of water caused the accident, from the idea that nothing else could account for it. The strain caused by the varying temperature of the internal tubes in Cornish or Lancashire boilers, and the difficulty of staying their flat ends so as to make them sufficiently secure without being too rigid to allow for the expansion of the tubes, render them liable to corrosion or "furrowing" in particular lines of strain, the destructive action of which is very rapid; while the large quantity of brickwork around the outside, necessary to form the external flues, also renders them liable to corrosion in the parts most difficult of access. In this favourite form of boiler therefore careful and frequent examination in every part is more needed than in boilers of simpler form and setting; and the increasing number of explosions among these boilers seems to establish that they are only trustworthy if frequently examined and kept in perfect order.

Several instances have occurred of explosion of Portable Crane Boilers. Their small size has led to their condition being disregarded, under the idea that scarcely any pressure could burst them. In practice it is found however that they are often exposed to greater pressure than other boilers, because the fire is large and quick in proportion to their size; and they often have to stand for a considerable time with the steam up, and their exposed position and long intervals of rest add to the chances of corrosion, as shown by the example in Fig. 28, Plate 58. The large manholes without strengthening rings, that are so often put in these boilers, have been the cause of explosions such as that shown in Fig. 29. The same remark applies to some of the portable or agricultural boilers which have exploded, such as those shown in Figs. 30 and 31.

Much mischief is often caused by bad imitation of well planned boilers. Thus in boilers of the Cornish form, the ends are made sometimes so rigid as to give no allowance for the expansion of the tube, and the result is such continued strain as to cause constant leaking and the consequent risk of fracture. In furnace boilers the tops of the crowns of the inside tubes are often made flat, as in Fig. 37, Plate 59, instead of being domed; or the inside tube is of undue size, as in Fig. 21, Plate 56. Furnace boilers have been made with the omission of the stays that are so peculiarly necessary in that form, whereby both ends have been left free to bulge outwards with the pressure, as in Fig. 32, Plate 58.

Cornish boilers are often altered to the plain cylindrical form, without compensation being made for the loss of strength caused by the removal of the tube; this has led to such explosions as shown in Fig. 33, where two tubes were taken out, and Fig. 34, where one tube was taken out. One of the most frequent and serious causes of loss of strength is the repairing of externally fired boilers. Not only are the patches sometimes only bolted on in a temporary manner, as in Fig. 35, Plate 59, but even where they are rivetted on there is an entire want of bond or crossed joint, as in the case of the exploded boilers shown in Figs. 15, 16, and 17, Plates 54 and 55, and Fig. 36, Plate 59.

An attempt is made in Fig. 38 to show the effect of wear and tear of boiler plate in an ordinary upright furnace boiler, such as is shown in Fig. 37. The external surface is exposed to intense heat and consequently expands, while the internal surface is kept cool by contact with the water and expands to a much less degree. The continued repetition of this process produces the same effect of cracking the surface as that seen in the anvil blocks of steam hammers; and the strength of the plate is reduced in proportion to the destruction of the continuity of its surface. The deleterious effect of this process is much increased if the boiler is subject to alternate heating and streams of cold air on opening the fire-doors. To avoid it the flame should have room to spread over as large a surface as possible, without impinging on one particular point, and the firing should be as regular as possible; and hence the greater freedom from injury in boilers mechanically fired or heated by gas. The above action is quite distinct from the overheating of the plates that occurs when no water is in contact with them, which simply softens them and reduces their strength, as in Fig. 39. It is believed that many boilers suffer from overheating without being short of water: and an attempt is made to show this action in such an upright boiler as is represented in Fig. 37, by the enlarged section of the side shown in Fig. 40. The flame is shown impinging on a limited surface, as before, and the steam rises so rapidly from the inner surface as to maintain a continuous stratum of steam between the iron and the water, and the plate consequently becomes overheated at that part. When the intense flame subsides by an alteration of the working of the furnace, the stream of steam diminishes, and the water returns and suddenly cools and contracts the plate, but often not before it has commenced to get out of shape. This has perhaps led to the explosion shown in Fig. 59, Plate 61. The same thing may happen to the crowns of tubes of internally fired boilers when over fired, as in Fig. 41, Plate 59. Success has attended the use of internal linings to boilers, arranged so as to ensure a rapid circulation over the most heated parts, and also to catch all the mud and loose scale.

In order to enable boiler minders to make proper periodical examinations, it is necessary that care should be taken to arrange both the boilers and the flues with that view; and this can be done without materially injuring the efficiency of the boiler. Ordinary plain cylindrical boilers can be entered easily, as in Fig. 42, Plate 60; and although the small spaces between the tubes and the shells of Cornish and Lancashire boilers, as shown in Fig. 43, render the complete examination troublesome, there is no difficulty in seeing those parts most likely to need examination, such as the crowns of the tubes and the end plates and angle iron. It is in the external flues that greater accommodation is needed, as in many cases these are so narrow that the boiler is quite inaccessible without pulling down the brickwork, as in Figs. 44 and 45. The loss of heating effect caused by the use of wider flues is so little, that it is far outweighed by the greater security obtained from the more efficient examination that is thereby rendered practicable. The flues of the plain cylindrical boiler are easily made wide enough for a man to pass through them. The flues of Cornish and Lancashire boilers should be made as shown in Figs. 46 and 47, so that a man can enter them without such inconvenience as in Fig. 48. One point of danger being the use of wide mid-feather walls, on which corrosion is apt to take place, these should be narrowed and the weight of the boiler supported on side brackets; the top of the mid-feather and side walls can then be constructed with sight-holes as at A A in Figs. 49 and 50, so as to give the means of examining the plates near each seam by simply removing loose bricks.

The explosions of fourteen Domestic or Heating-Apparatus Boilers are included in the list of explosions, Table III; and some notice is required to be taken of these, because they have led to the loss of the lives of those who could not be expected to know their construction or how to guard against accident; and as these boilers are seldom seen or examined after they are once set, they should be the more carefully constructed. In one or two cases these boilers were of a rectangular shape, as in Fig. 51, Plate 61, ill adapted to bear internal pressure, and yet placed in connection with cisterns in the roofs of lofty houses, so as to expose them to a hydrostatic pressure almost up to their bursting strength without any addition of steam pressure. The most usual cause of explosion is the lighting of the fire during frosty weather in a house that has been left vacant, so that steam pressure accumulates in the boiler whilst the exit is frozen up, as was the case in Fig. 52. The cast-iron boilers commonly used, Fig. 53, are capable of bearing but little pressure; and the wrought-iron boilers, as in Fig. 54, are found often so badly welded as to be but little stronger; but even if they were as strong as they could be made, the stoppage of the pipes by ice would lead to explosion. Steam pressure may be guarded against by a safety valve; but as this may become set fast in a little time, it would be far better to avoid all chance of steam accumulation by such an arrangement as that shown in Fig. 55, where the circulating boiler is placed within an open-topped boiler behind the kitchen fire, and only receives its heat through the hot water surrounding it, and therefore cannot itself become sufficiently hot to generate steam.

A few remarks may be useful as to those faults arising in working which fall under the department of the boiler minders. Not a few of the explosions during the last four years have occurred from acts of simple carelessness, such as where a blow-off pipe was left open, so that the boiler was nearly emptied of water while at work; or in another case where two boilers were fed at the same time through a common pipe without a back valve, and the water from one "kicked" over into the other. Undue pressure has been allowed to accumulate by safety valves being tied down, as in the agricultural boiler, Fig. 56, Plate 61; or by an extra weight being put upon the safety valve, as in an instance where three bricks were fastened to the lever and the fires were lighted earlier than usual, under the idea that an accumulation of steam could be raised during the night to make a good start in the morning. Another explosion was caused by working a boiler at more than three times its proper pressure to meet a temporary emergency. In not a few cases of explosion there was no pressure gauge on the boiler, or the gauge was out of repair in consequence of being placed on the steam pipe, so that it vibrated with every stroke of the engine; as in the examples shown in Figs. 24 and 16, Plates 57 and 54.

Corrosion has been the direct cause of many of the explosions. In one or two cases the corrosion was known to exist, but the renewal of the boiler was too long delayed, as in Fig. 57, Plate 61; in others it took both owners and minders by surprise, as in Fig. 1, Plate 52. It is said that to produce rapid rusting of iron there must be present oxygen, water, and carbonic acid; and as all these are present in a boiler flue when there are leaks, it is not surprising that so many cases occur of explosions from corrosion.

Much mischief is often done by the injudicious use of compositions in the boiler that are designed to prevent incrustation, especially where there is no blow-off cock or where its use is neglected. A hard deposit on the boiler plates is, in the writer's opinion, not so injurious as the soft and muddy deposit produced by the use of such compositions. A hard scale is equivalent to thickening the plate; and although this is sufficiently mischievous, the injury to the plates is much more rapid when a thicker but spongy deposit entirely prevents contact of the water and impedes the transmission of the heat. An attempt to illustrate this is given in Fig. 58, Plate 61, which is an enlarged view of a portion of such a boiler as is shown in Fig. 37. The money spent in boiler compositions would be better applied in securing a supply of proper water, or in filtering and purifying the water before it enters the boiler.

The writer has had to mention only faults in boilers; but it is not to be inferred that all boilers are working in actual danger. A very small percentage perhaps are so; but without periodical examination no one can feel sure of the condition of any boiler. It is not likely that explosions in future will be from exactly the same causes as those now described, because the known faults will be avoided. For instance no new Balloon, Wagon, or Butterley boilers are now made; and the peculiar faults and the weakness of the tubes in Cornish and others of the better classes of boilers are now so well known as to be generally avoided; and as information spreads, many evils will become things of the past.

As periodical examination has been so strongly advocated, it might seem natural to desire that it should be enforced by government authority; but this is by no means recommended. A select parliamentary committee has been recently investigating the subject, with a view to ascertain whether that would be desirable, but has adjourned for the session without coming to any decision on this point. Even if a perfect system of government inspection could be contrived and perfectly administered, it would have the effect of taking the responsibility from the owners, who are the natural guardians of the safety of their boilers. Although the loss of 70 lives per annum by boiler explosions is sufficiently deplorable, the deaths by railway accidents are more than three times that number; yet very little inspection of railways is held to be necessary, and that inspection takes place chiefly before the commencement of working or after accidents. A coercive system may introduce more evils than it cures, especially as at present so much difference of opinion exists respecting the causes of boiler explosions. In the opinion of the writer, far more real good arises from the calm discussion of the facts and from the spread of correct information by such societies as this Institution, than from enforcing by law any action which is not perhaps believed by the majority of steam users to be at all necessary or useful. It has been at times suggested to increase the power and responsibility of coroners in holding inquests upon those killed by boiler explosions, by requiring them to obtain scientific evidence and to insist that the causes of the explosions shall be added to the verdicts of juries. But it is believed that this would only encumber an important institution, because a jury who might well decide whether a person had been killed by any criminal carelessness would not be a suitable tribunal to decide between possibly conflicting scientific evidence; and also, as an inquest may result in a verdict of manslaughter, the eliciting of information on such an occasion is checked by the natural fear of inadvertently involving some one in so serious a charge. The public at large, and steam users generally, would gain more information and guidance from the scientific evidence itself than from the verdict of a coroner's jury; and it is believed much good has resulted in preventing locomotive boiler explosions by publishing the reports of the government inspecting engineers, who have gained their knowledge of the facts in conversation with all those concerned, and have added recommendations which have been promptly acted upon.

The writer's object has been that the boilers found most convenient and best suited for the different purposes for which they are used should be made to work with safety, rather than that reliance should be placed upon the qualities of any particular kind of boiler or fittings. No form of boiler at present admits of absolute reliance upon its freedom from risk.

The following general conclusions appear to arise from the consideration of the records of boiler explosions.

1. That the force accumulated in an ordinary boiler is enough to account for the violence of an explosion.

2. That no form of boiler, however well constructed and fitted, is free from the liability to explosion, if allowed to get out of order; and that boilers which bear the hydraulic test may still be dangerous.

3. That the condition of a boiler can be satisfactorily ascertained only by periodical examinations, and that no boiler should work without being thoroughly examined at short intervals.

4. That the cost of periodical examination is so little as to be far outweighed by the greater security obtained; and that the settings of all boilers should be constructed with a view to facilitate examination.

5. That the surest way to make systematic examination general is to spread as widely as possible correct information as to the facts and ascertained causes of boiler explosions, and to inform boiler owners and minders what dangers to guard against; and that this is preferable, and more likely to lessen explosions than enforcing any system of inspection by legal enactment.

TABLE I.

[redacted] *f Records of Steam Boiler Explosions*
up to 30th June 1870,
[redacted] Description of Exploded Boilers.

	Explosions up to June 1866.			Explosions in the 4 years from June 1866 to June 1870.			Total Explosions up to June 1870.		
	English.	Foreign.	Total.	English.	Foreign.	Total.	English.	Foreign.	Total.
[redacted] . .	57	263	320	12	64	76	69	327	396
[redacted] es .	140	1	141	84	3	87	224	4	228
[redacted] . .	91	29	120	10	68	78	101	97	198
[redacted] . .	114	2	116	54	3	57	168	5	173
[redacted] h- .	62	2	64	5	2	7	67	4	71
[redacted] nall	28	1	29	17	17	34	45	18	63
[redacted] . .	14	...	14	22	14	36	36	14	50
[redacted] . .	10	...	10	8	...	8	18	...	18
[redacted] . .	203	29	232	7	175	182	210	204	414
[redacted] . .	719	327	1046	219	346	565	938	673	1611

TABLE II.

Summary of Records of Steam Boiler Explosions
up to 30th June 1870,
showing Causes of Explosions.

Causes of Explosions.	Explosions up to June 1866.			Explosions in the 4 years from June 1866 to June 1870.			Total Explosions up to June 1870.		
	English.	Foreign.	Total.	English.	Foreign.	Total.	English.	Foreign.	Total.
Worn out, corroded, or burnt plates	92	53	145	89	5	94	181	58	239
Undue pressure, overloaded valves, intentional or from carelessness	132	5	137	25	6	31	157	11	168
Bad construction, weak tubes, defective fittings or stays, or want of repair	136	108	244	69	8	77	205	116	321
Shortness of water, formation of scale or mud, or external flues set too high	106	8	114	28	2	30	134	10	144
Extraneous causes, lightning, fire, gas, &c. . . .	6	3	9	2	...	2	8	3	11
Too uncertain to be classified	247	150	397	6	325	331	253	475	728
Totals	719	327	1046	219	346	565	938	673	1611

TABLE III.

Analysis of Steam Boiler Explosions in the United Kingdom during the Four years ending 30th June 1870, showing the Causes of Explosion of Boilers of different descriptions.

A = Faults in construction or repair.
B = Faults which should be detected by periodical examination.
C = Faults which should be prevented by careful attendants.
D = Causes extraneous or uncertain.

E = number of Explosions. **K** = number of persons Killed. **I** = number of persons Injured.

Cornish, Lancashire, or other Boilers with internal flues.

		E	K	I						
A	Weak tubes	26	17	41						
	Weak combustion chambers	5	8	7						
	Weak ends	3	10	10						
	Weak dome	1	0	0						
	Weak manhole	1	1	1						
	Bad repair	3	5	2	E	K	I			
					39	41	61			
B	External corrosion	18	42	101						
	Internal corrosion	6	4	5						
					24	46	106			
C	Shortness of water	14	11	23						
	Scale or mud	3	1	0						
	Undue pressure	4	14	4						
					21	26	27	E	K	I

		E	K	I	E	K	I	E	K	I
	Marine Boilers.									
	Brought forwards							138	167	289
A	Weak flues	3	6	3						
	Weak ends	2	6	5						
	Bad material	1	3	1	6	15	9			
B	External corrosion	2	10	3						
	Internal corrosion	3	1	4	5	11	7			
C	Shortness of water	1	11	7	1	11	7	12	37	23
	Locomotive Boilers.									
A	Boiler used as frame for engine	2	1	2	2	1	2			
B	External corrosion	2	1	4						
	Internal corrosion	2	0	3	4	1	7			
D	Broken connecting-rod pierced boiler	1	2	1						
	Dome caught by railway bridge	1	1	0						
	Uncertain causes	2	0	4	4	3	5	10	5	14
	Agricultural Boilers.									
A	Weak manhole	1	1	4	1	1	4			
B	External corrosion	2	3	3						
	Internal corrosion	1	1	7	3	4	10			
C	Shortness of water	1	0	0						
	Undue pressure	6	15	15	7	15	15	11	20	29
	Furnace-upright Boilers.									
A	Too much flame on one part	1	2	0						
	Frequent repair producing seam rip	1	13	2	2	15	2			
B	External corrosion	2	13	11						
	Internal corrosion	2	15	6	4	28	17			
C	Shortness of water	2	3	8	2	3	8	8	46	27
	Elephant Boilers.									
A	Weak ends or want of stays	1	2	2	1	2	2			
B	External corrosion	1	0	4	1	0	4	2	2	6
	Carried forwards							181	277	388

		E	K	I	E	K	I	E	K	I
	Brought forwards							181	277	388
	Crane Boilers.									
A	Weak manhole	3	7	3	3	7	3			
B	External corrosion	1	4	2	1	4	2			
C	Shortness of water	2	2	0	2	2	0	6	13	5
	Rag Steamers, &c.									
A	Weak manhole	3	2	5						
	Bad material	1	1	5						
	Want of stays	1	1	0	5	4	10			
C	Undue pressure	1	2	6	1	2	6	6	6	16
	Feed-water Heaters.									
D	Uncertain causes	2	0	6	2	0	6	2	0	6
	Domestic Boilers.									
A	Weak shape	3	4	7	3	4	7			
B	Corrosion	2	0	5	2	0	5			
C	Undue pressure from freezing of pipes	9	7	9	9	7	9	14	11	21

Balloon Boilers.

TABLE IV.

Summary of Causes of the Steam Boiler Explosions comprised in Table III.

Causes of Explosions.	E Number of Explosions.	K Number of persons Killed.	I Number of persons Injured
A Faults in construction or repair . .	95	128	167
B Faults which should be detected by periodical examination	62	105	185
C Faults which should be prevented by careful attendants	54	79	84
D Extraneous or uncertain causes . . .	8	3	14
Totals	219	315	450

Mr. Marten exhibited an extensive collection of specimens of corroded plates from boilers that had exploded, showing the effects of external and internal corrosion under different circumstances; and specimens of plates that had been overheated, by the flame impinging too strongly upon a particular spot. He exhibited also a very extensive and interesting series of photographs of explosions, together with models of various constructions of boilers, and others illustrating some of the most destructive explosions.

The Chairman enquired what rules of strength were generally adopted at the present time in the construction of boilers.

Mr. Marten said he believed that in stationary boilers of 6 or 7 feet diameter, and working at an average pressure of 40 or 50 lbs., the general practice was to use plates about 3-8ths inch thick: there was not found to be much advantage in having them thicker, because the iron deteriorated more quickly in the thicker plates, from the heat passing less rapidly through them.

The CHAIRMAN remarked that with those proportions the limit of strength of a boiler would be only about five times the strain it was subjected to in working, allowance being made for rivet holes; which seemed to leave rather a small margin of safety.

Mr. L. E. FLETCHER was sure they must all feel much indebted to the author of the very interesting paper that had been read, for the great amount of light he had thrown upon a subject upon which not long ago there had been a great deal of mystery and confusion, steam boiler explosions having been attributed to various conjectural causes, such as magnetism, galvanism, and electricity. Such theories were now entirely dispelled, as shown by the present paper, which traced the explosions to their true causes; and he quite agreed with the views expressed, that all boiler explosions were to be attributed simply to neglect in some form or other. The whole of the results produced by a boiler explosion were due to the immense force of the steam pent up in the boiler, the amount of which had not been fully realised until recently. From the researches however of Rankine, Joule, and Airy, the amount of force that could be generated in a steam boiler was now capable of being measured; and according to Mr. Airy, one cubic foot of water heated to the temperature of steam at 60 lbs. pressure per square inch would develop, when suddenly liberated from pressure, as much force as 1 lb. or 2 lbs. of gunpowder. This amount of force was amply sufficient to account for all the disastrous effects attending a boiler explosion, and therefore all mysterious causes might be dismissed at once, and every explosion might be traced to neglect on the part of either the owner, the maker, or the minder of the boiler. It was very common to attribute explosions to the boiler minder, which was easily explained by the owner and maker combining to throw the blame upon the weaker party. He had found that for one explosion really due to the boiler minder six explosions were due to the maker or the owner, more frequently the latter. As to the explosions from malconstruction, most even of these he considered should be attributed to the owner rather than the maker, on account of the reluctance frequently met with to pay a proper price for a really good boiler. If good boilers were procured and were also well looked after in working, there would be an end to the terrible catastrophes hitherto occurring, for which he considered the boiler owners were really responsible. In the recent public investigations of the subject of boiler explosions, it had been admitted as now established that explosions could be prevented by means of proper examination of boilers, by which any weak places could be found out in time to avert danger. The question remaining therefore to be decided was, how was the proper examination of boilers to be secured throughout the country. This was required to be effected in such a manner as to suppress explosions but not to embarrass the users of steam; and he considered the best way would be to require by legislative enactment that every steam boiler should be periodically examined and certified as safe, and that no boiler should be allowed to be used which was not so. The actual examination however he thought had better not be in the hands of the Government, in order to avoid any risk of the freedom of steam users being unnecessarily restricted as to the construction of boiler employed.

With regard generally to the strength of boilers, he considered that a boiler of 7 feet diameter, made of plates 7-16ths inch thick with single-rivetted longitudinal joints, was safe to work at 60 lbs. pressure; double-rivetted it would be safe up to 70 or 80 lbs. For this pressure the furnace tubes of Cornish or Lancashire boilers should be strengthened with stiffening rings at all the circumferential seams of rivets. It was desirable that every boiler should be provided with two glass water-gauges, so that one might act as a check upon the correctness of the other; and the feed-pipe should always be furnished with a back valve, to prevent any risk of the furnace crowns being laid bare by the water escaping at the feed inlet into another connected boiler, or by leakage in the feed pipe. There should be two safety-valves, one to act in case either of over-pressure or of low water, while the other safety-valve should be of external dead-weight pendulous construction; there should also be a steam pressure-gauge to every boiler, and a blow-off cock at the bottom of the boiler.

Mr. R. B. Longridge said he fully concurred in the main with the views advanced in the paper that had been read, and could confirm the statements as to the number of explosions and the causes of them. From the experience of the Association with which he was connected for the inspection and insurance of steam boilers, it had been found that nearly 30 per cent. of the explosions which occurred were to be attributed to negligence of the attendants, about 30 per cent. to wear and tear, and 40 per cent. to malconstruction. It had also been found that where boilers were periodically examined the risk of explosion was greatly reduced: taking the whole of the explosions that had occurred during the past eleven years, the proportion of explosions had only been 1 in every 4,600 of the boilers that were periodically examined, while of boilers that were not inspected the number of explosions during the same period was 1 in every 2,000. The explosions which had occurred during the same period among the boilers that were insured had included 10 plain cylindrical boilers and 10 Cornish boilers; but as the plain cylindrical boilers were only 15 per cent. of the entire number, while the Cornish were about 75 per cent., the result was very much in favour of the Cornish boilers, the safety of these being thus shown to be practically five times that of the plain cylindrical boilers, whereas the opinion expressed in the paper had been that the latter were much the safer. In regard to the remark which had been made as to the comparatively small number of explosions that were really due to the negligence of the attendants, his own experience had led him to quite a different conclusion, as he had found that 30 per cent. of the explosions occurred from negligence on the part of the attendants; and on this account, whatever means might be adopted for examining boilers, he thought it would be impossible ever to succeed in entirely preventing explosions, although there could be no question that the number of them might thereby be reduced to a very great extent.

What he had himself found to be the cause of more trouble in the working of boilers than anything else, had been the occurrence of overheating of the plates, not from any deficiency of water, but merely from deposit upon the plates. Where the water contained carbonate of lime in considerable quantity, he had found it nearly impossible to keep boilers in good condition, especially if there were any grease or oil in the water, as was generally the case when the feed water was heated by the exhaust steam from the engine, the steam bringing over with it particles of grease and tallow from the cylinders; in such instances he had found it impossible to prevent leakage taking place.

Mr. F. J. Bramwell enquired why water containing carbonate of lime was more injurious to boilers when the feed water was heated by direct mixture with the exhaust steam, as in non-condensing engines, than when it was pumped from the hot well of an ordinary injection condensing engine; and whether it was more injurious than the water returned to a boiler from a surface condenser, which consisted of the condensed steam alone without any mixture of fresh water.

Mr. R. B. Longridge replied that the reason why water containing carbonate of lime was more injurious to a boiler when heated by the exhaust steam of a non-condensing engine was that, when so heated, it carried over a much larger proportion of grease into the boiler than was the case where the feed water was supplied from the hot well of a condensing engine. The same results occurred indeed with condensing engines, though not to the same extent; he had met with instances where the boilers of condensing engines had to be stopped time after time for repairs, and it had been impossible to keep them in order. Ultimately the only remedy had been found by feeding the boilers with fresh cold water, instead of from the hot well, and by blowing-off from the surface of the water in the boilers so as to get rid of the carbonate of lime; after that plan was adopted there had been no further trouble, and the boilers had worked for some years up to the present time without any trouble.

The Chairman enquired whether in describing the effects of water containing carbonate of lime, a distinction was intended to be made between carbonate and sulphate of lime.

Mr. R. B. Longridge replied that the sulphate of lime sank in the water and formed a hard scale, which was not so injurious to the plates; but the carbonate of lime being light rose to the surface, and mixing with any grease upon the surface of the water, gradually settled on the plates at the water level, and dried hard there, forming a thick coating and preventing the contact of the water; the plates consequently became red-hot in some cases, although there was abundance of water in the boiler.

The Chairman suggested the possibility of the injurious results having been produced by carbonate of magnesia, which was often present in water with carbonate of lime; it was the carbonate of magnesia he believed which rose to the surface of the water, while the carbonate of lime sank to the bottom. His own experience with boilers had been that carbonate of magnesia was more injurious to the plates than carbonate of lime; it was very commonly present with carbonate of lime, and where the two were present together it was easily mistaken for carbonate of lime. He enquired from what geological formation the water had been taken that was found so injurious in the boilers.

Mr. R. B. Longridge replied that one of the worst cases had been at Scarborough, where the boilers were supplied with water from the limestone. The material deposited upon the boiler plates at the surface of the water had been analysed by Dr. Roscoe, Dr. Angus Smith, and other chemists, and had been found to be principally carbonate of lime; it contained of course some carbonate of magnesia, but the greater proportion was carbonate of lime.

The Chairman said the results of chemical analysis must necessarily be accepted; but from the large quantity of carbonate of magnesia known to be contained in the Scarborough water, he was inclined to think the injurious action upon the boiler plates was really to be attributed to this, rather than to the carbonate of lime.

Mr. T. R. Crampton observed that the question of corrosion in steam boilers was a most important one, and in consequence of the very serious results to which corrosion had led he considered the great object to be aimed at was to prevent it from taking place at all, whatever the nature of the water employed. Commercially he did not think it was advantageous to work high-pressure condensing engines at so high a pressure as was now often employed; and notwithstanding that in surface-condensing engines the exhaust steam was all returned to the boiler, he believed it was practicable effectually to prevent any corrosion occurring in the boilers. He had himself lately succeeded in accomplishing this object with a pair of small condensing engines, employed for pumping water, having upright cylinders of 18 inches diameter and 20 inches stroke; steam was supplied by two small Cornish boilers, and by means of surface condensers the same water was used over and over again, and the vacuum regularly obtained was as much as 29½ inches of mercury. These engines had now been at work nearly four years, and particular care had been taken to prevent any grease getting into the boilers; the pistons were made practically steam-tight by a number of light rings presenting a small rubbing surface against the cylinder, and the stuffing-boxes were packed with a packing made of cotton with a little asbestos and French chalk, so that no grease whatever was supplied either into the cylinders or the stuffing-boxes for lubrication. The water in the boilers was from the chalk formation in Kent, and had only twice been blown off with an interval of two years; the water had never been changed except on these two occasions of blowing off, and the leakage that took place was very small indeed; on looking into the boilers about two months ago, after they had been constantly at work about fourteen months since last blowing off, he had found the surface of the plates looked quite black, and showed no signs of corrosion or pitting in any way. The reason he considered was that no fatty acid had been able to find its way into the boiler, as no grease at all was used in the cylinders; and he believed if any grease had been used in the cylinders it would have been impossible to work the boilers with the same success. In order to do altogether without grease in the cylinders it was only necessary in practice that the cylinders should be placed upright, in which position the friction was least; and the pistons could be made effectually steam-tight by baffling the steam with a number of light packing rings, which together presented but a small extent of rubbing surface and caused so little friction as to dispense with lubrication by fatty matter. The engines he had described were working at

10 horse power each, and the consumption was 2·8 lbs. of coal per horse power per hour, 8 lbs. of water being evaporated per lb. of coal. The whole of the cylinder surfaces were carefully steam-jacketted, and all steam surfaces well lagged. The pressure of steam employed was 30 lbs., and the effective expansion was five times. In the same engine he had used 60 lbs. steam with a proportionate degree of expansion; but with no better results in economy, as there were losses attending high expansion that neutralised the gain. These very successful results showed that condensing engines could be advantageously worked with surface condensers, without grease either in the cylinders or the stuffing-boxes, and without corrosion in the boilers; and he thought accordingly that if a little more attention were paid to this subject by the users of boilers, it would tend greatly to prevent many of the accidents at present occurring.

Mr. D. ADAMSON remarked that the numerous examples of explosions given in the paper clearly illustrated the fact that the first rupture in a boiler was the important thing to be provided against; and he considered there was great room for the further application of sound mechanical principles, for preventing one part of a boiler pulling against another in consequence of the existence of unbalanced strains or unequal distribution of the heat. Wherever the greatest strain occurred in a boiler, it should be met by a proportionate increase in the strength of the structure, so as to give an equal degree of security in all the parts; but he thought it was a mistake to aim at security by insisting upon some particularly high tensile strength in the boiler plates employed, because this was necessarily accompanied by a degree of brittleness and hardness in the iron which rendered such plates unsuitable for boiler work. The shell of a boiler should not be subjected to a greater tensile strain he considered than 4 tons per square inch of section; and therefore a cylindrical boiler of 7 feet diameter, made of plates 7-16ths inch thick with double-rivetted joints for the longitudinal seams of the boiler shell, was quite safe for working at 60 lbs. pressure, without coming near that limit of strain. Where there was much liability to corrosion however, he thought it was preferable to take 2 tons per square inch of section as the safe limit of tensile strain. As the seams of boilers were the parts where the deterioration of strength by corrosion, leakage, and wear and tear mainly took place, it was important that their number should be reduced as much as possible; a considerable advance had indeed been already made in this direction, the number of seams in Cornish and Lancashire boilers having originally been 2½ times as great as in boilers of the same class constructed by himself at the present time; but a further material reduction in the number of joints might still be effected by the use of larger plates than had hitherto been generally employed. In a boiler 8 ft. 6 ins. diameter which he had recently made under the advice of Mr. George Salt for Messrs. Ambler's works at Bradford, to work at 100 lbs. pressure, the entire circumference of the shell was made of a single large steel plate 27 feet long and 3 ft. 3 ins. wide, having consequently only a single longitudinal double-rivetted joint in each of the lengths of which the boiler barrel was composed; these plates, weighing 16 cwts. each, had been made for the purpose at the Bolton Iron and Steel Works, and similar large steel boiler-plates were being rolled also at the Barrow Works. What was wanted in boiler plates was a uniform quality of metal and regular thickness, with a considerable degree of flexibility; if the iron was of irregular quality or the plates irregular in thickness, a boiler would destroy itself from these defects sooner than it would be destroyed by the action of the fire. The punching of the rivet holes had been found to reduce the strength of boiler plates as much as 21 per cent. in the case of steel plates, and nearly as much in Low Moor plates, but not more than 7 or 8 per cent. in the less stubborn Staffordshire plates; but even the last amount of reduction was too much to lose by the destructive process of punching; and he therefore made a practice of drilling all the rivet holes through both plates together in the boilers that he constructed, so as to avoid impairing the strength of the plates, and to enable the joints to go together with complete accuracy.

In boilers having internal flues, the external pressure would be certain sooner or later to collapse the flues if there were the slightest departure from the true circle in their shape; and it was therefore important not to trust to the permanency of the correct structural form, but to strengthen the flues irrespectively of their configuration, and to make some provision for limiting the distance over which a collapse if it did occur could extend, particularly in the case of long flues. Previously to the experiments of Sir William Fairbairn in reference to the subject of collapse of tubes under external pressure, he had himself already made about two hundred boilers having the flues strengthened by being put together with flanged seams, whereby flues 30 feet long were divided into nine or ten distinct lengths, and were thus supported rigidly at frequent intervals, so that if a collapse ever did occur it would be restricted to the short portion of flue between two of these supporting rings. The liberation of the steam pressure would thus be comparatively slow, and the disastrous effects consequent upon the suddenness and magnitude of ordinary explosions would be avoided. In internally-fired boilers, it was desirable that all joints formed by two thicknesses of plates should be removed from the action of the fire, and this could only be accomplished by using flanged seams for the circular joints of the flues, in which case the double thickness of plates was immersed in the water; and if steel plates were used with the longitudinal seams double-rivetted, care should be taken to keep these seams below the action of the fire, on account of the unequal strains that would be occasioned by double and single thicknesses of plates. Another point of construction, which had been attended with much practical difficulty, was the connection of the flat ends of boilers to the shell and the flues; and his own experience had led him to the conclusion that it was a mistake to rivet thin flue plates to the thicker end plates without increasing the thickness of the flue ends to the same thickness as the end plates themselves. The gusset stays uniting the end plates to the shell of the boiler should not come nearer the flues than 8 or 9 inches, measuring from the outer circumference of the flue; the difficulty was to control in the best way the springing of the end plates under pressure without rendering them too rigid, and this was the mode of construction which he had found the most successful in accomplishing that object. In the testing of boilers he considered it was very important to take care that the testing strain was not carried so high as to produce any permanent set in the iron of the plates. The plan he had adopted for testing boilers as to any permanent expansion had been to stretch a thin steel ribbon round the boiler shell, and draw a fine straight line across the two ends of the ribbon where they came together, and then observe whether the two lines coincided when the pressure was removed after the testing; by this means he had found that up to a tensile strain of 7 tons per square inch of section of metal the elasticity of the iron was not exceeded, and on the pressure being removed the boiler shell came back to its original dimensions without any permanent set having taken place.

He could confirm what had been said as to the great trouble experienced from carbonate of lime or carbonate of magnesia uniting with any grease in the boiler, and forming a thick "floury" coating over the plates, which effectually kept the water away from them wherever it settled upon them. When a quantity of this sediment, commonly known as "flour powder," was placed in a ladle and heated, a great quantity of grease contained in it was rapidly made manifest; and he believed it was the mixture of the grease with it which enabled it to spread itself along the sides of the boiler at the water level and adhere to the plates. The evil thus occasioned by the presence of grease in boilers might be considerably mitigated, he considered, if cylindrical balanced valves were more generally used, instead of the flat slide-valves commonly employed in steam engines; by that means the quantity of lubricating material required for the valves would be greatly reduced, and less grease would be carried into the boiler when the feed water was heated by the exhaust steam. Where good water was hard to get for boilers and surface condensation was also difficult, he thought it might be desirable to work at a higher pressure of steam, even up to as much as 130 lbs. per square inch, in order to get the greatest advantage out of a boiler; but under ordinary circumstances he considered 80 to 100 lbs. was quite as high as was advisable for the regular working pressure in stationary steam boilers. Some of the most disastrous explosions of boilers had occurred from want of uniformity in the temperature of the water in internally-fired boilers, where the water had remained nearly cold at the bottom of the boiler below the fire during the time that the boiler was standing before commencing work in the morning; and he thought therefore it was a very desirable precaution in such boilers to blow off a quantity of water from the bottom during the time occupied in getting steam up and before commencing work in the morning, in order to stimulate the circulation of the water and distribute a more equal temperature throughout the boiler.

Mr. H. T. FERGUSON said he had taken some interest in boiler explosions in Cornwall, and having had opportunities of examining several boilers that had exploded there, he had in every instance found the explosion had resulted from sheer neglect. The clumsy screw patch shown in Fig. 35, Plate 59, was a specimen of the dangerous way in which he had seen boilers patched in that district. During the past year he had visited eight explosions; and in one case, after having obtained permission to photograph an exploded boiler, he was not allowed to proceed to do so, as the owner objected to the bad state of the boiler being made known. Many of the explosions in Cornwall occurred from the want of glass water-gauges, or some other means of ascertaining the height of the water in the boiler besides the two gauge-cocks now in use.

Mr. F. A. PAGET remarked that Cornwall illustrated the weak side of voluntary inspection, because the boilers were there scattered so far apart that the expense of inspecting them would be considerably increased as compared with Lancashire; and he thought therefore voluntary inspection would not be likely to prove effectual in such a district as Cornwall, and that some other plan would have to be adopted there. In reference to the internal corrosion of boilers, he believed that with steel boilers, on account of the homogeneous nature of the metal, no instance had been met with where the plates showed that peculiar form of corrosion called "pitting," which had frequently proved a source of danger in ordinary iron boilers.

Mr. W. Ford Smith believed the introduction of distilled water with the feed water was an effectual means of preventing deposit in boilers, and he had recently witnessed an instance where distilled water had been introduced with the feed water into a boiler and there had been found to be a very small amount of incrustation in consequence. In this case, which had been under his own notice for eight years past, a double-flued boiler was supplied with the Manchester town water and rain water, and the exhaust steam with all the grease contained in it was blown into a cistern, from the bottom of which the feed water, probably free from grease, was taken to supply the boiler. The two flues were both perfectly free from incrustation, and seemed as clean as when first put to work, which he believed was mainly due to the use of the distilled water from the exhaust steam. The incrustation of boiler plates by deposit from the water was a very important point in connection with boiler explosions, and it was most desirable that it should be prevented as much as possible.

Mr. L. Olrick concurred in the remarks which had been made as to the great evils occasioned by the presence of bicarbonate of lime, commonly known as carbonate of lime, in the feed water supplied to steam boilers; and one method that had been adopted for preventing the formation of deposit consisted in removing the carbonate of lime from the feed water by Dr. Clark's process of precipitation. This plan had been applied with success to a boiler at Bury St. Edmunds, where the water supplied for the feed contained 30 grains of carbonate of lime per gallon. This water was pumped into a tank 6 feet high and 2 feet diameter, and from another tank of smaller diameter lime water specially prepared was constantly running into the large tank, which had the effect of precipitating the carbonate of lime originally contained in the feed water, by the incoming lime disengaging the carbonic acid contained in the bicarbonate, and thus converting the soluble bicarbonate into insoluble carbonate of lime. The greater part of the lime sank down to the bottom of the mixing tank, and the water, which was then of a slightly milky colour and containing the flakes of lime, was drawn off near the bottom of the tank, and filtered into another tank partially filled with small pieces of coke as a filtering material, through which the water ascended slowly to the top of the tank, where it was drawn off for use in the boiler. If the water was required for drinking purposes, it was, in addition to the above filtration, passed through a second filter of animal charcoal, by which the organic impurities contained in the water were removed. Means were also provided for removing the coke periodically from the filtering tank when it had become charged with lime, and replacing it with fresh coke, by having a loose cylindrical casing to contain the coke inside the filtering tank. In this way the filtration was so completely effected that during the two years that this process had been in operation no trouble whatever had been experienced with the boiler, which worked free from danger, as there was an absence of any hard scale on the plates. The boiler was opened once in every three months, and a little dust that had accumulated was swept out, which was all that had accumulated from the water during that time of working. Previously a hard scale of an inch thickness used to be formed in three weeks' time, which had been very difficult to remove and had necessitated a great additional consumption of fuel and loss of time in cleaning.

An instance of the danger that might be occasioned by deposit from the feed water had come under his notice in the case of a well so much softened by the overheating as to be collapsed by the steam pressure. The feed pipe was afterwards continued horizontally along the water level in the boiler to a distance of 3 feet beyond the fire bridge, and a "rose" or nozzle was put on the end of the pipe, having a number of small holes to distribute the feed water thoroughly on entering the boiler; and no further collapse of the flue had since taken place. In this instance the feed water was largely charged with carbonate of lime, causing an extremely hard and impermeable deposit in the boiler. He thought however that, instead of pumping into steam boilers water impregnated with all sorts of impurities which would form thick layers of scale on the plates, and then removing this by means of hammers or boiler compositions, it would be far preferable in every case to adopt the simple plan of cleansing the water completely of all deposit before it entered the boiler. This might be accomplished in a variety of ways, and would be attended with a considerable saving in fuel, while much of the danger ordinarily incurred in the working of steam boilers would be avoided.

Mr. W. RICHARDSON thought the observations made in the paper and illustrated by the diagrams exhibited, in reference to facility of examining steam boilers, were likely to mislead a little; from his own experience he considered that such a construction and mode of setting as were shown in Fig. 42, Plate 60, though having the advantage of rendering the boiler easy to examine, were not conducive to its safe working, because having once had a number of externally fired boilers he had found great difficulty in keeping them in a safe condition, on account of their being liable to the formation of deposit over the fire, or to rupture by contraction if cold water ever entered the boiler. Also in Figs. 46 and 47, in which the external flues were represented as made so large that a man could enter them upright, he did not see how any ordinary chimney could be capable of producing draught enough through such large flues to render the combustion sufficiently active for raising steam; and therefore, though flues of large sectional area would be advantageous in one respect, they would be bad in regard to the regular working of the boilers.

The means of providing for the use of impure feed water for steam boilers was a subject of very great importance. At Oldham, where Messrs. Platt's works with which he was connected were situated, the town stood on a high hill, from 500 to 800 feet above the sea level, with no river near; and the only water supply was obtained from higher ground at a considerable distance, and was so limited in amount that there was not more than was required to supply the town for domestic purposes; and they were therefore obliged to obtain their supply of water from the foul water running down the drains. In order to purify this very dirty water sufficiently to render it in the first instance suitable for condensing purposes, they had constructed a series of three reservoirs, the first for the earthy matters to settle down, the second supplied from the overflow of the first, and the third from the overflow of the second. The supply of injection water for the condensers was taken from the third reservoir, and was returned into the second. The boiler feed was taken from the hot well, and was forced through a number of vertical cast-iron vessels, strong enough to bear an internal pressure of 100 lbs. per square inch, the regular boiler pressure being 75 lbs. Midway in the height of each vessel a layer of calcined bones was placed upon a perforated plate or grating, and the dirty water from the hot well was driven upwards from the bottom through the mass of bones by the feed pump; in this way it was so thoroughly cleansed of all impurities as to be fit to pass direct into the boiler from the top of the purifying vessel. The water from the hot well was so dirty, that the layer of bones would become choked with sediment and filth in only half a day; and it was therefore necessary to cleanse them twice a day, which was done in the dinner hour and at night by blowing steam down from the top in the opposite direction through the bones, by which means they were thoroughly cleansed and made ready for use again. The thickness of the layer of bones was about 3 feet, and after a year's constant working they were found to have settled down only about 1½ inch. This was the plan they had adopted for their condensing engines, for which a continuous fresh supply of clean feed water had to be obtained from the foul water of the drains.

For the non-condensing engines, in order to get back heat and water from the exhaust steam and feed the boilers with clean hot water, a supply of water was taken from the last of the settling reservoirs into a covered cistern 6 feet long by 3 feet wide and 6 feet deep, the height of the water in the cistern being regulated by a ball cock so as to be kept 9 inches below the cover. On the top of the cover stood at one end a vertical cylindrical feed-water heater, 30 inches diameter and 12 feet high, fitted with tubes like a locomotive boiler or a surface condenser; and on the other end of the cistern cover stood a vertical pipe 20 inches diameter and 30 feet high, open to the atmosphere at the top. A circulating pump lifted the water from the cistern to the top of the vertical pipe, within which it then fell down in a shower back into the cistern again. The exhaust steam discharged from the high-pressure engines passed down through the inside of the tubes in the feed-water heater, then over the surface of the water in the cistern, and escaped up the vertical pipe, where it met the falling shower of water from the circulating pump. By this means the water in the cistern became heated up to 170° Fahr., and was supplied at that temperature to the boiler feed-pump, by which it was forced through a bone filter, like that already described of the condensing engines, and thus purified was then made to pass outside the tubes of the feed-water heater, and entered the boiler at the temperature of 210° Fahr. In this way a supply of clean feed water was obtained, heated up almost to the boiling point, from the exhaust steam discharged by the non-condensing engines. With this arrangement for purifying the feed water, the boiler was now only cleaned at holiday times, four times a year; but before adopting this method, the boiler used to have to be cleaned every week or fortnight, and was very seldom allowed to run more than the fortnight. The quantity of deposit got out now that the boiler was cleaned four times a year was not so much at each time of cleaning as was formerly got out in a month; and the saving effected in the coal consumption and labour had paid the interest of the outlay expended in thus getting over the difficulty of obtaining clean feed water for the boilers from a supply of dirty water.

The Chairman enquired what kind of water it was that the town was supplied with, and what was the size and construction of the boilers, and the length of time they had been working on that arrangement.

Mr. W. Richardson replied that the water was moss water obtained from boggy ground on hills at some distance from Oldham and above the cultivation level. The boilers were 6 ft. 6 ins. diameter and 30 feet long, with a single flue 3 ft. 10 ins. diameter extending a length of 23 feet, beyond which they were multitubular for the remaining 7 feet. Some of these boilers had now been working regularly for nine years, and at the present time they had forty boilers in use, all of which, with the exception of two, were made of steel plates; there had been no difficulty or extensive repairs with them, and they continued working quite satisfactorily.

Mr. W. Ford Smith enquired what was the appearance of the boilers inside, after working with the feed water cleansed in the manner that had been described.

Mr. W. Richardson replied that there was very little incrustation upon the plates. In addition to cleansing the feed water, they used also a vegetable substance obtained from Finland, which he understood was the decayed root of a tree; this was boiled down with a little directly to the bottom, and thereby causing the bottom plates to contract suddenly and to crack and leak. In some cases they had put a length of as much as 30 feet of feed pipe inside the boiler, and this had been completely successful in preventing fracture or leakage of the bottom plates.

Mr. W. Bouch observed that the paper which had been read, and others upon the same subject on previous occasions, had quite done away with the fanciful theories formerly entertained respecting the causes of steam boiler explosions, and had brought out clearly the simple fact that explosions resulted only from the rupture of material which was not strong enough to bear the strain put upon it. As the disastrous effects attending an explosion were due to the sudden liberation of a confined volume of water heated to a very high temperature, some boilers had been specially constructed with the object of reducing to a minimum the volume of water contained in them, and raising the proportion of heating surface to a maximum, so as to enable the boilers to maintain the required production of steam from the small quantity of water. In such boilers the sudden liberation of the contents by the failure of any part could take place without any serious consequences, as was the case in locomotive and other multitubular boilers, where the bursting of a tube was attended with none of the disastrous results of a boiler explosion. He thought therefore that the principle of the locomotive boiler might advantageously be applied for stationary boilers to a much larger extent than was at present the case. Prior to the year 1849 he had experienced much difficulty in locomotive boilers of the old Stockton and Darlington class, with internally-fired flues, from the detrimental effects occasioned by concentration of the heat upon particular portions of the flues; and this had led him at that time to develop, in conjunction with Mr. Adamson, the flanged flue, strengthened at intervals along its length by flanging the plates outwards at the circular joints and inserting a stiffening ring to which the two plates at each joint were rivetted. The application of this flanged flue had since then been very successfully and extensively carried out by Mr. Adamson for all stationary boilers having flues subjected to external pressure. In the working of locomotive boilers his experience was that it was not safe to keep them in full work longer than six years without a thorough examination of the tubes, firebox, and shell, the tubes requiring to be all taken out for this purpose. It was true that in particular cases there might be evidence that the extreme measure of pulling the tubes out was not then necessary; but as a general rule, when an engine had attained that age and had been working about 100 miles per day, it ought not to be allowed to continue running until it had undergone a very thorough examination in that manner.

Mr. F. J. **Bramwell** alluded to the "quicksilver engine" that was put to work in two steam vessels by Mr. James Howard in London about twenty-five years ago, in which no more water was contained in the boiler at any one time than was required for one stroke of the engine; and when the engine was standing there was not any water in the boiler at all. The boiler was made with a double bottom, and the space between the inner and outer plates was filled with an alloy of quicksilver and lead, which was kept heated to a high temperature by the fire directly underneath; the inner boiler plate had deep indentations in it, dipping down into the alloy, so as to increase the extent of water-heating surface. The feed-water was injected into the boiler at each stroke of the engine by the feed pump, the quantity injected being accurately adjusted to

DESCRIPTION OF A SELF-ACTING SAFETY AND FIRE-EXTINGUISHING VALVE FOR STEAM BOILERS.

BY MR. GEORGE D. HUGHES, OF NOTTINGHAM.

The object of this Valve is to secure Steam Boilers from injury or explosion arising either from over-pressure of steam or from deficiency of water. The great increase that has taken place in the use of steam power, and the continued demand for steam of higher pressure, render the safe construction and working of steam boilers a matter of special importance; and the writer having been many years engaged in the superintendence and inspection of steam boilers has had his attention frequently called to serious accidents and explosions that have been caused by the inefficient working of the boiler mountings in general use—namely the safety valves, water gauges, and low-water indicators—from the failure of which the majority of accidents have arisen. Although many different constructions of fusible plugs and low-water alarums have been tried, the result has been only a partial success; and this has been shown by the experience of the steam boiler inspection and insurance Associations, which have reported numerous instances of accident and explosion from these causes. Out of fifty-four cases of explosion occurring last year, nine were attributed to deficiency of water, and the desirability of adopting self-acting valves for indicating danger from low water was specially pressed upon the attention of boiler owners in the reports of the associations for that year; and in several instances, it is stated, serious explosions involving great loss of life and property might have been prevented by their adoption. Safety valves and water gauges are also frequently found inefficient; and during last year upwards of eight hundred safety valves and three hundred water gauges were reported as being out of order by one association alone. A large number of boilers are also injured from these causes, of which nothing is heard except by the owners or those immediately connected with them; and from the writer's experience the largest number of these cases may be attributed to deficiency of water. The repeated failure of fusible plugs, low-water indicators, and safety valves, from inefficient action or from admitting of being tampered with by unskilful, careless, or ignorant attendants, has become a matter for serious consideration.

In the apparatus forming the subject of the present paper, which has been designed by the writer and Mr. Sellers for removing the above sources of accident, the object has been to provide a means of preventing any risk of the pressure of steam exceeding the intended limit, or the water in the boiler falling below the proper level, either through accident, neglect, or wilfulness. The apparatus is self-acting, and acts directly upon the boiler fire, beginning to damp it as soon as the limit either of pressure or of water-level is passed, and continuing to increase in action until the pressure of steam is brought down to the proper limit; or, in the case of low water, causing the fire to be ultimately extinguished before any injury can occur to the boiler from overheating of the furnace-crown or flues. At the same time the further action of the apparatus can be arrested at any period of its operation, by giving the required attention to the boiler, either by supplying feed-water or by easing the pressure; and the boiler is then at once ready for regular work again, without any delay beyond that required for getting up the fire. The only cause from which injury or danger can arise—namely the boiler fire—is thus directly acted upon and kept under complete control, by self-acting means that are entirely beyond the control of the attendant and can only be stopped in action by giving the required attention to the boiler.

In Figs. 1 to 6, Plates 62 to 64, are shown end and longitudinal elevations of the apparatus as attached to the most general type of boilers in use, namely the Cornish or Lancashire and the Plain Cylindrical boilers.

In Figs. 1 and 2, Plate 62, is shown a combined external safety valve and fire-extinguishing valve, as applied to a Lancashire boiler. The fire-extinguishing valve A of spherical form is placed in a steam chamber B on the top of the boiler, from which pass steam pipes CC to the crowns of the furnaces D D. The valve is loaded internally by a dead weight E, consisting of cast-iron plates, suspended from it by the slotted rod F. When the pressure of steam exceeds the load on the valve, the steam escapes into the chamber B and down the pipes C C into the furnaces. A horizontal lever G is suspended inside the boiler by means of a loose-fitting brass pin I in its centre, and carries a float H suspended at one end, which is balanced on the surface of the water by the weight K at the other end of the lever. This lever passing through the slot in the valve-rod F raises the valve A when the float descends with the water level, thereby allowing the steam to escape through the valve into the chamber B, and thence down the pipes C into the furnaces in the same manner as in the case of over-pressure, thus relieving the pressure and damping the fires at the same time. In combination with the fire-extinguishing valve A a second safety valve L is also provided, which is loaded externally by the lever and weight M, and is adjusted to blow off at a pressure somewhat lower than that at which the internally loaded valve is adjusted. This double valve, as shown in Figs. 1 and 2, is adapted for new boilers, combining the common external safety valve with the fire-extinguishing valve.

In Figs. 3 and 4, Plate 63, are shown similar views of a single external valve, as applied to a Plain Cylindrical boiler with egg ends. The fire-extinguishing valve A is loaded internally by the dead weight E, as before, and discharges the steam through the steam pipes C opening into the furnace D; the float H and lever G open the valve whenever the water level falls too low. The valve thus acts in the same way as the one already described, damping the fire and relieving the pressure in case of either deficiency of water or over-pressure.

In Figs. 5 and 6, Plate 64, are shown end and longitudinal views of the arrangement of a single internal valve, chiefly recommended for facility of attaching it to the boiler. This valve being attached to the upper part of the shell of the boiler by means of the two studs S S can be readily fixed in a few hours, the steam pipes C C being attached in the same manner as shown in Figs. 1 to 4.

The arrangements shown in Figs. 3 to 6 are adapted for boilers already provided with one efficient external safety valve of the usual description. It is preferred, in all cases where practicable, for the valves to be attached to the boilers by rivetting, as more efficient and less liable to leakage or derangement than bolted joints.

This safety apparatus has now been in use for a year and a half, and a considerable number of the valves are now in regular work. They have thus far proved successful, and there has not been any instance of their failing to act whenever the pressure or water level passed the intended limit. The position of the apparatus entirely clear of the water, and the simplicity of its construction, render it quite free from risk of being obstructed by accumulation of scum or sediment in the boiler; and the valve is free from risk of sticking in its seat through accidental causes, and cannot be tampered with in any way by the attendant. The discharge steam pipes over the fire are not exposed to any risk of choking up by soot or other deposit, as they continue filled with air without any current through them; and they are cleared out by a jet of steam whenever the boiler is blown off under pressure. There is not any risk of danger to the fireman from steam blowing out at the firedoor when the apparatus is in action, as the chimney draught carries the whole of the steam jet forwards into the flue, and no steam escapes at the firedoor, even when the full discharge from the escape pipe is taking place.

A special advantage experienced with this apparatus is that, even in the extreme case of the boiler fire being extinguished in consequence of shortness of water, the works driven by the boiler are only stopped until the boiler is pumped up and the fire got up again; but in the case of a fusible safety-plug being melted in consequence of shortness of water, the steam has to be all blown off and the boiler cooled down enough to allow of replacing the plug, after which the steam has then to be raised again, causing altogether a serious stoppage of the works driven. In reference to the use of fusible plugs it may be remarked that they are generally considered not safe to be relied upon for acting with certainty in case of shortness of water, owing to the liability of incrustation forming upon them sufficient to protect them from melting until too late to preserve the boiler from injury; and in the writer's experience many cases have occurred of explosions of boilers and collapse of furnace crowns from shortness of water, where fusible plugs had been provided but had failed to act in time. Some forms of boiler, such as the plain cylindrical, do not indeed admit of fusible plugs being fixed in any way satisfactory for ensuring their action. The apparatus now described is offered as a simple and convenient means of effectively preserving boilers of any form from risk of danger or injury owing either to shortness of water or to over-pressure.

Mr. Hughes exhibited specimens of the safety valves, of both the double and the single construction, showing their mode of action in steam boilers.

The Chairman enquired how many of these safety valves were now at work, and how long any of them had been in use.

Mr. Hughes replied that there were now upwards of sixty of the valves in use, the first of which had been applied at his own works in Nottingham about eighteen months ago, and had never been taken to pieces or cleaned in any way since starting; the pipes leading from the valve to the furnace crowns remained clean inside, free from soot. Several others of the valves could also be seen at other works in Nottingham.

The Chairman enquired whether the fire-extinguishing valve opened suddenly, or only slowly so as to dribble the steam upon the fire at first.

Mr. Hughes replied that the valve opened very slowly at first. In the case of low water, a slight hissing was all that was observed at first, but in five minutes the steam blew a good deal harder; and it would then go on in that way for three quarters of an hour in most cases before the fire would be completely extinguished. It thus gave the attendant ample time to examine the feed pump in case of any temporary derangement, and get the boiler filled up; and as soon as the pump was got to work, the valve gradually closed. By this means the boiler was kept at work without intermission; whereas with a fusible plug, when the water level fell too low the plug was melted, and the boiler had to be stopped and cooled down and the manhole opened for getting inside to fix a new plug, causing a serious inconvenience by the stoppage of the works. With every pressure of steam the low-water valve acted in the same way with equal efficiency. If the engine was stopped suddenly, causing the pressure to rise beyond the working limit, the valve would also in that case act in the same manner, blowing off slowly at first, and gradually increasing in action until the spring balance of the external safety valve was slacked back for relieving the pressure; and as long as the steam continued above the working pressure, it would continue to escape through the valve and damp the fire.

The Chairman enquired whether any corrosion of the boiler plates had been occasioned by the steam issuing in small quantities over the fire.

Mr. Hughes said that no corrosion had been noticed from that cause in any of the plates in the furnace of the boiler that had been longest at work with this fire-extinguishing valve. The valve was indeed only expected to come into action under extreme circumstances. In the case of the double valve, shown in Figs. 1 and 2, the external safety valve was set to blow off at 5 lbs. less pressure than the internal dead-weight valve; so that unless the external valve was tampered with, the internal valve discharging the steam over the fire was never called into action for excess of steam pressure, but only in the event of low water. If the attendant endeavoured to increase the pressure in the boiler, by hanging an extra weight on the external valve or otherwise overloading it, then the internal valve would blow off and put out the fire.

Mr. H. **Chapman** enquired whether any provision was made for preventing the attendant from wilfully plugging the discharge pipes of the internal valve, and thus preventing its coming into action when the external safety valve was overloaded.

Mr. **Hughes** said it was of course possible to stop the action by such means, but it would be impossible to prevent any mechanical contrivance being put out of order by wilfulness.

The **Chairman** asked whether the internal valve was found liable to leak; if it leaked, there would be a continual escape of steam into the furnace.

Mr. **Hughes** replied that he had not found any of the valves leak. The internal valve was made spherical, and its seating also spherical, so that it closed steam-tight in any position; and there was nothing to cause it to stick, as the spindle attached to it did not pass through any guide but served merely to suspend the weight from it. The external valve was made with a flat bearing surface, instead of conical. Both the internal and external valves were carefully made of hard gun-metal, and with a very small bearing surface, amounting to only 1-32nd inch width for each inch in diameter, so that a valve of 3 inches diameter had only 3-32nds inch width of bearing surface. With this small amount the valves were found to act very accurately, blowing off exactly at the pressure to which they were loaded, as indicated by a pressure gauge; but he had found that the ordinary safety valves with wide bearing surfaces were not to be depended upon.

Mr. L. E. **Fletcher** considered it very desirable that the use of fusible plugs should be superseded by some contrivance more reliable than they were, as he had not found much confidence could be placed in them; they were apt to go off when they should not, and not to act when they should.

The **Chairman** moved a vote of thanks to Mr. Hughes for his paper, which was passed.

The CHAIRMAN moved a vote of thanks, which was passed, to the Proprietors of the various Works in Nottingham and the neighbourhood, who had so liberally opened their Works, and so handsomely received the Members on the occasion of the present Meeting; to the several Railway Companies, for the special facilities they had so kindly afforded to the Members for attending the Meeting and the Excursions in connection with it; and to the Committee of the Mechanics' Institution, for their kindness in granting the use of the building for the purpose of the Nottingham Meeting.

The Meeting then terminated.

In the afternoon a number of Lace and Hosiery Manufactories, Machine Works, &c., in Nottingham and the neighbourhood were visited by the Members.

In the evening the Members and their friends dined together, in celebration of the meeting of the Institution in Nottingham.

On Thursday, 4th August, an Excursion was made by the Members to the Butterley and Codnor Park Iron Works, and the Ripley and Great Britain Collieries.

On Friday, 5th August, the Members visited the Midland Railway Locomotive Works at Derby, and the Burton Brewery Works of Messrs. Allsopp and Sons and Messrs. Bass and Co.

On Saturday, 6th August, an Excursion was made by the Members to Lincoln, to visit the Agricultural Implement Works of Messrs. Clayton and Shuttleworth, Messrs. Robey and Co., and Messrs. Ruston and Proctor.

PROCEEDINGS.

10 November, 1870.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 10th November, 1870; C. William Siemens, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

John Ramsbottom,	Crewe.

VICE-PRESIDENTS.

(Six of the number to be elected.)

John Anderson,	Woolwich.
I. Lowthian Bell,	Newcastle-on-Tyne.
Frederick J. Bramwell,	London.
Thomas Greenwood,	Leeds.
Thomas Hawksley,	London.
Sampson Lloyd,	Wednesbury.
Walter May,	Birmingham.
William Menelaus,	Merthyr Tydvil.
John Robinson,	Manchester.
C. William Siemens,	London.

COUNCIL.

(*Five of the number to be elected.*)

Peter D. Bennett,	Westbromwich.
Henry Bessemer,	London.
William Clay,	Birkenhead.
Edward A. Cowper,	London.
Sir Charles Fox,	London.
W. Montgomerie Neilson,	Glasgow.
William Richardson,	Oldham.
Charles P. Stewart,	Manchester.
Francis W. Webb,	Bolton.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

The Chairman announced that the Ballot Lists had been opened, and the following New Members were duly elected:—

MEMBERS.

Anthony Bower,	Liverpool.
Nicholas Proctor Burgh,	London.
James Carver,	Nottingham.
George Roberts Cowen,	Nottingham.

ON THE WARSOP AERO-STEAM ENGINE.

By Mr. RICHARD EATON, of Nottingham.

The principle of this engine, which is the invention of Mr. George Warsop of Nottingham, consists in injecting a continuous supply of heated air into the bottom of the boiler, whereby the water in the boiler is kept in a constant state of agitation throughout; and the result is found to be that the generation of steam is rendered more rapid, with considerable economy in the fuel consumed, while incrustation in the boiler and priming are prevented. The air, compressed to the boiler pressure by an air-pump driven by the engine or by a separate donkey engine, is conveyed to the boiler through a set of heating pipes fixed in the boiler flues or smokebox, and is thus heated to a temperature of about 600° Fahr. by heat which would otherwise escape to the chimney as waste. The heated air enters the boiler through a longitudinal pipe extending along the entire length of the bottom of the boiler, and perforated on the under side with a series of small holes for distributing the air throughout the water in the boiler. This air rising up continuously through the water has the effect of diminishing its cohesion, and causes a more free ebullition of the water, and at a boiling point somewhat lower than the ordinary temperature due to the pressure. The heated air injected into the boiler has moreover a direct evaporative action upon the water, equivalent to an increase of heating surface in the boiler; and this increase has an extra efficiency from the circumstance of the air being in direct contact with the water, instead of the heat being communicated through the medium of imperfectly conducting metal plates.

The mode in which the arrangement is carried out in stationary boilers is shown in Figs. 1 and 2, Plates 65 and 66, which represent a Cornish boiler 6 feet diameter and 20 feet long that has been working nearly a year on this plan at Messrs. Thackeray's factory, Nottingham; and a similar boiler is also working at Chatham Dockyard. The compressed air from the air-pump is conveyed by a wrought-iron pipe A, 1½ inch bore, which traverses four times along the length of one of the side flues of the boiler; and then enters the front end of the boiler through a check valve C. The pipe B for delivering the air lies close along the bottom of the boiler, and is perforated along its under side with a series of small holes, 1-16th inch diameter, for the discharge of the air into the water; the holes are situated at gradually diminishing intervals from the front to the closed back end of the pipe, so as to distribute the heated air equally throughout the length of the boiler. The air is compressed by a pump worked by a donkey engine, the pump being a vertical single-acting cylinder 7 inches diameter, with a stroke varying from 6½ to 8 inches, and working at an average speed of 80 strokes per minute. The quantity of compressed air injected into the boiler is adjusted to about 12 per cent. of the volume of steam generated.

In the earlier applications, the proportion of air injected was rather greater, amounting to 16 per cent. of the steam; and a more complicated heating apparatus was employed with the view of pump that no further effective heating could be obtained from the exhaust steam.

In Figs. 4 to 6, Plates 67 and 68, are shown a new engine and boiler that were subsequently constructed in London at Messrs. Easton and Amos' works, for the purpose of testing the effects of the air injection on a larger scale, and with a new boiler well constructed for economy of working with ordinary steam. The boiler is of Cornish multitubular construction, 4½ feet diameter and 14 feet long, having a single fire-tube and fifty-six 2½ inch tubes beyond. The engine is vertical direct-acting, working a compressing air-pump E, Fig. 6, 12 inches diameter with a stroke ranging from 6½ to 12 inches. This air-pump, which is shown to a larger scale in Fig. 7, is single-acting with a solid piston, and has brass conical valves F F with very narrow bearing faces of only 1-32nd inch width; and on account of the quick speed of the engine, amounting to upwards of 120 revolutions per minute, the lift of the inlet valve is only 1-8th inch. The compressed air is conveyed from the pump along the pipe A A, Figs. 6 and 4, and is heated by passing it through a spiral coil of pipe G in the smokebox; and it is delivered into the boiler by a perforated distributing pipe B along the bottom, as in the previous cases.

The following are the results obtained as regards economy of fuel in the comparative trials of working alternately with and without the air injection in the boiler at Mr. Warsop's works, Nottingham, the power being measured by a friction-break dynamometer. Specimens of the indicator diagrams that were taken in the course of the trials are shown in Figs. 10, 12, and 13, Plates 70 and 71. In Fig. 10 the dotted lines show the working of the engine with steam alone, and the full lines with the steam and air combined, the break being loaded with 120 lbs. in both cases. The full line in Fig. 12 shows the air-pump resistance with the friction of the engine, the fine dotted line the friction of the engine alone, and the shaded diagram the friction of the engine with the unloaded break. In Fig. 13 are shown two compression diagrams taken from the air-pump; and in this pump the effective length of stroke was shortened to the required extent by an opening being made in the side of the cylinder at about two thirds of the length, in consequence of the pump not being provided with the means of altering the length of stroke of the piston for adjusting the quantity of air delivered by the pump.

The comparative experiments were started in each case with the same boiler pressure of 50 lbs.; the fire was then all drawn, and one cwt. of Welsh coal of moderate quality was supplied, and the engine was started and kept running as long as that quantity of fuel would supply steam to give a speed of 90 revolutions per minute; the water level was kept the same in all the trials, both at the beginning and the end of each experiment. The results were that the time the engine could be kept running was 112 minutes with steam alone, and 153 minutes with the steam and air combined; and the total number of revolutions got out of the break was 10,500 with steam alone, and 15,433 with the combined steam and air, showing a gain of 47 per cent. with the air injection. The boiler pressure at the end of the trials was 38½ lbs. with the steam alone, and 44 lbs. with combined steam and air, the excess in the latter case being due to the extra resistance of working the air-pump. The pressure of air in the pipe at the air-pump was throughout about 1½ lbs. greater than the boiler pressure at the same time, this difference being due to the height of the column of water in the boiler above the point at which the air entered, thus showing that there was not any sensible loss of power from friction of the air in its passage.

In similar trials made with the London engine shown in Plates 67 and 68, the supply of fuel was in each case 2 cwts. of ordinary engine coal, the steam pressure at starting was 55 lbs., and the engine was stopped when the speed fell to 100 revolutions per minute; the load on the break was 204 lbs., and gave an effective power of 19½ horse power. The time of running was 101 minutes with steam alone, and 131 minutes with combined air and steam; and the total revolutions of the break were 11,797 and 15,752 respectively, showing a gain of 33 per cent. with the air injection. In another trial of the same engine at a slower speed, maintained at the uniform rate of 117 revolutions per minute throughout, the result was a gain of 24 per cent. in the work done with the air injection from the same weight of fuel. In both these trials however there was a defect in the air-pump from leakage of the piston, which caused a waste of power; and the effect of the leakage being greater when running at the slower speed, the result was a deficiency in the supply of air to the boiler in the latter trial, accounting for the difference of 9 per cent. in the comparative gain with the air injection.

The air injection has been in use for nearly a year in a screw coasting steamer, the *Fox* of Middlesbrough, having a pair of high-pressure engines 15½ inches diameter and 13 inches stroke, with a vertical boiler loaded at 60 lbs. pressure. In a voyage from Middlesbrough to Aberdeen a comparative trial was made in two successive periods of five hours each, working in one case with steam alone, and in the other with combined steam and air, the circumstances being practically similar in the two cases. The consumption of coal was then found to be 345 lbs. per hour with steam alone, and 271 lbs. per hour with combined steam and air, showing an increased consumption of 27 per cent. without the air injection.

In another screw steamer, the *Fuh-le*, which has gone out to China, the result of using the combined steam and air is stated by the captain to be a saving of 30 per cent. in the fuel. This steamer has a pair of cylinders 20 inches diameter and 18 inches stroke, and a pair of multitubular boilers loaded at 90 lbs. per inch. The boilers are shown in Figs. 8 and 9, Plate 69, and heat the air by means of four transverse lines of pipe A A in the smokebox.

In the case of condensing engines, the air injected into the boiler causes an addition to the quantity to be removed by the condenser air-pump; but the proportion of the air being only one eighth of the volume of the steam, taking the volume of the compressed air before heating, the result is only a reduction of about 2 lbs. per square inch in the condenser vacuum. This is shown by the indicator diagrams in Fig. 11, Plate 70, which were taken from a condensing engine at

Messrs. Easton and Amos' works, Erith, with 15½ inch cylinder and 24 inch stroke; the two dotted lines were taken with steam alone, and the two full lines with combined steam and air.

Two advantages of great practical importance, which are found to attend the use of the air injection in steam boilers, are the prevention of incrustation and of priming; both of which are prevented to a very remarkable and complete extent.

With respect to incrustation, the result of nearly a year's working of the Nottingham boiler shown in Figs. 1 and 2, Plates 65 and 66, is that the interior of the boiler, which was new at the commencement of the trial, continues quite clean, and without incrustation at any part. A similar boiler however, which had been used at the same works up to the time of starting the present one, and had been supplied with the same feed water, was covered throughout with incrustation, to such an extent that it was the regular practice to put in ½ cwt. of soda every six weeks and blow off the boiler for keeping down the incrustation. With the present boiler there was a period of about a month during which the air injection was not in use, in consequence of some alterations being made in the machinery; and it was found that a coating of incrustation of nearly ⅛ inch thickness had been formed over the whole boiler surface below the water line during that period, the boiler having been quite clean at the commencement of the period. The boiler was again examined about four months after the air injection had been again applied, and it was then found quite clean, the incrustation that had been formed having been quite removed by the action of the air injection. It is submitted that the constant agitation of the water caused by the continuous injection of air along the whole length of the bottom of the boiler, and the supply of carbonic acid gas that is necessarily introduced with the air, act as a means of preventing incrustation, partly by mechanical suspension and partly by chemical solution of the sediment in the water.

In marine boilers the action of the air injection is of still greater value, by preventing the saline incrustation that causes so serious a difficulty in the working of marine boilers with high pressure. In the case of the *Fox* steamer previously mentioned, the boiler was examined whilst discharging cargo at London after having worked continuously for three months with the air injection, the only blowing-off during the time having been from the scum cock; and it was found that there was no incrustation in the boiler thicker than 1-16th inch. In a similar steamer however, the *Lynx*, which was working on the same course, and was exactly similar to the *Fox* except that it had not the air injection, the extent of saline incrustation was so serious that it was found impossible to run a week without opening the boiler and cleaning the incrustation out. The incrustation of 1-16th inch that had been formed in the boiler of the *Fox* during its three months' work was found to be in two distinct layers, corresponding to two occasions on which the compressing air-pump had been out of action for about twelve hours owing to defects in the machinery.

In the *Fuh-le* steamer previously referred to, it was reported by the captain on arrival at Ceylon from England that the use of the air injection had kept the boilers free from incrustation; but that in a similar vessel which had made the same voyage, the boiler was found to be so completely salted up as to necessitate a delay of some days for cleaning it out.

With respect to the prevention of priming by the use of the air injection, an experiment was made on the *Fox* steamer in a voyage between Middlesbrough and Aberdeen: whilst running at 112 revolutions of the engines per minute with 60 lbs. boiler pressure and no priming, the air injection was suddenly shut off, and within two minutes water began to pass over into the cylinders, and in three minutes the speed of the engines had fallen to 100 revolutions; the air injection was then turned on again, and in three minutes all priming had ceased, and the engines had recovered their speed of 112 revolutions. On another occasion, when in full run with a speed of 126 revolutions per minute and 60 lbs. boiler pressure, the compressing air-pump became disabled for some hours by an accident; and it was immediately found necessary to reduce the boiler pressure to 30 lbs. on account of priming, and a speed of 90 revolutions was all that could be maintained in consequence.

A similar occurrence took place with the *Fuh-le* steamer, in which with the air injection a working pressure of 80 lbs. was maintained without priming; but on one occasion when the air-pump was some hours out of work, the priming was so great that no higher pressure could be maintained than 35 lbs., until the air injection was again applied.

In the case of a screw yacht, the *Naiad*, having a single 8 inch cylinder, and a vertical multitubular boiler working up to 70 lbs. pressure, in which the air injection is applied, a series of experiments were tried for the purpose of endeavouring to excite priming, by sometimes pushing the boiler, sometimes throwing in fresh water and salt water in different proportions, and sometimes letting the fire down and then firing up in great haste; but in every case the result was a complete freedom from priming. Directly the air injection was shut off however, an excessive priming took place, and it was found impossible to work the boiler at a higher pressure than 35 lbs.

The facts which have now been given with reference to the prevention of earthy or saline incrustation and of priming, show that the use of the air injection is not only an important advantage in the working of boilers, but will increase their durability and diminish the liability to explosions. A collateral advantage is also found in the time required for getting up steam in large boilers; for as soon as steam enough is obtained to start the donkey engine that works the air-pump, the rate of raising steam becomes rapidly increased.

With regard to the action of the air injection, it may be remarked that, as pointed out by Professor Tyndall, when heat, or in other words motion, is added to water, the particles on its free surface fly off in gradually increasing numbers; and at length what is called the boiling point of the liquid is approached, where the conversion into vapour is not confined to a free surface, but is most copious at the bottom of the vessel where the heat is applied. All water holds a quantity of air within it in solution, but by boiling the water this imprisoned air may be liberated; the presence of this air in the water promotes the ebullition of the liquid by acting as a kind of elastic spring, pushing the molecules apart, and thus helping them to take the gaseous form. The cohesion of the water is vastly augmented by the removal of the air; and this very cohesion enables the liquid to resist ebullition, to such an extent that water freed of its air can be raised to a temperature of 60° or 80° Fahr. above its ordinary boiling point without ebullition. In the ebullition of water, the cohesion between its particles, induced by the water having been deprived of its air, is often overcome by fits and starts; which may be so augmented by the introduction of certain salts into the liquid, that the detachment is in some cases so sudden and violent as to cause the liquid to leap bodily out of the vessel, as in the case of priming. It is submitted that the effect of the air injection, which forms the subject of the present paper, is to facilitate the liberation of the particles of steam from the water in the boiler, and so prevent this injurious action in boiling.

Mr. Eaton said that, with respect to the formation of saline incrustation, experiments had been made at Nottingham with artificial salt water of more than double the strength of the saltest sea water, and it was found that the boiler remained entirely free inside from saline incrustation; but outside, wherever there was any little leakage at the cocks or otherwise, the usual deposit of salt was found the same as in marine boilers. He exhibited a specimen of this saline incrustation obtained from the outside of the boiler, together with a sample of the water employed in the experiment. He showed also a specimen of the incrustation that had been formed in the boiler of the "Fox" steamer upon the two occasions referred to in the paper, when the application of the air injection had been temporarily suspended for some hours; the specimen showed distinctly the two separate thin layers of which it was composed, corresponding to the two periods of working without the air injection. He showed another specimen of the ordinary thick incrustation found in marine boilers, which had been taken from a marine boiler undergoing repairs; and stated that the shipbuilder in whose yard the vessel lay had expressed his opinion that, if the air injection were only satisfactory in preventing incrustation, its value would be so great as to ensure its universal adoption for marine boilers. Subsequent experience had disclosed the other important advantage attending the air injection, namely the prevention of priming; and in order to ascertain the extent of its efficiency in this respect, a severe test had been resorted to in a boiler at Messrs. Daglish's works, by putting oatmeal into the boiler; it was then found that so long as the air injection was continued no priming occurred, but immediately upon the air being shut off the priming became so severe that the engine had to be stopped. He showed also a specimen of incrustation from the former boiler at Messrs. Thackeray's, referred to in the paper as having been worked without the air injection and having been supplied with ½ cwt. of soda every six weeks for keeping down the incrustation; and stated that the owner was so thoroughly satisfied with the success of the air injection in the similar boiler now working there, shown in Fig. 1, that he was about to apply it to all the boilers of the other engines at his works, including a condensing engine. A sample was exhibited of the foulest water that could be obtained from the bottom of a boiler provided with the air injection, after three months' continuous work without blowing-off, the boiler not having been furnished in that instance with a blow-off cock; and the particles of deposit were seen suspended in the water when shaken up, instead of having formed a scale upon the plates in the boiler. He stated that no fear need be entertained of any injury to the steam cylinder from solid particles being carried over in the steam when the water in the boiler had become so concentrated; for at the same time that the boiler was emptied and examined and the sample obtained of the water after the three months' working without blowing-off, the cylinder and piston and valves of the engine supplied by the boiler were examined, and were found to be quite bright, having sustained no injury from any escape of solid matter with the steam. He wished to bear testimony to the great amount of perseverance and industry which had been shown by Mr. Warsop, in working out this very valuable plan of air injection in steam boilers.

Mr. G. FOWLER said he had witnessed some of the experiments made by Mr. Amos that were referred to in the paper, and they had certainly been most carefully made and had proved very satisfactory in the results. The air cylinder in that case was the same diameter as the steam cylinder and was working with half the length of stroke and single-acting, so that the volume of air at atmospheric pressure which was pumped into the boiler in each revolution of the engine was one-fourth of the capacity of the steam cylinder. He had also seen the "Fox" steamer lying in the Thames after a three months' run with the air injection, and had examined the boiler, and the specimen of thin scale exhibited was a fair sample of what he had seen in the boiler. It was a vertical boiler somewhat like that shown in Fig. 3, and had three or four cross tubes; and the scale inside the boiler was spread pretty uniformly over the plates and the tubes, without any large masses of scale being collected at particular points.

Mr. E. B. MARTEN said he had recently seen the boiler working with the air injection at Messrs. Thackeray's works in Nottingham, Fig. 1, and was struck with the clearness of the water; the water in the gauge glass was perfectly clear, though the boiler had not been blown out then for some time. He had made enquiries about what had been the state of the boiler at the time that it was last blown out, and the statements given in the paper as to the entire absence of scale seemed to be completely borne out by the independent information he had obtained. He had examined also the similar boiler that had previously been working there without the air injection, and had seen the large amount of scale that had been formed upon the plates in ordinary working. There appeared to be something still to learn even about the seemingly simple process of boiling water; and observations that he had himself made, as well as those made by others, showed that the difficulty of boiling increased with the pureness of the water, and showed also the advantage of some nucleus for promoting ebullition, such as was afforded by projecting prominences upon the inner surfaces of the boiler plates, which had the effect of aiding in the liberation of the steam from the water, as though there were really some kind of adhesion between the steam and the water. The air injection seemed to supply what had long been wanted for steam boilers, namely a "boiler stirrer" to create efficient circulation, and aid in liberating the particles of steam. Another object frequently aimed at in the construction of boilers was to increase the extent of heating surface; but unless at the same time the extent of surface of the water for the ultimate escape of the steam was increased, the consequent priming became a great impediment to the usefulness of the boiler. With the air injection however each globule of heated air ascending in the water presented an independent steam-generating surface, and seemed therefore to be successful in preventing priming, besides increasing the extent of heating surface. He had been greatly pleased with what he had seen at Nottingham of the working of the air injection, and the facts given in the paper as to the advantages in prevention of incrustation and priming seemed to be fully borne out by the actual experience of the plan.

Mr. F. J. Bramwell considered the statements given in the paper respecting the results attending the air injection were of a very remarkable nature, and pointed to considerable economy, the cause of which however did not appear as yet to be explained satisfactorily. In regard to the comparative trials that had been made by working the same boiler with the air injection and without it, he enquired what had been the actual consumption of coal per indicated horse power per hour in the two cases; this was required to be known in order to judge of the real value of the economy due to the air injection, because if the engine were working badly before the air was applied, it would be more easy to improve its working than if it were originally working well. This was the first time that he had heard of the plan being applied to condensing engines, and he enquired whether its advantages were considered sufficient to compensate for the loss of vacuum in the condenser in consequence of the presence of the air in the steam. The indicator diagram Fig. 11 from the condensing engine showed only the diminution of vacuum due to the air, and he suggested that this vacuum diagram required to be supplemented by a further diagram showing the extra power required to work the condenser air-pump for maintaining that amount of vacuum with the mixed steam and air employed in the engine.

Mr. H. WOODS asked for some particulars respecting the boilers to which the air injection had been applied, with regard to their economy in working before the air-heating pipes were added. In the case of a boiler with a short firebox, or otherwise badly arranged for making use of the heat, there would be a great deal of heat escaping without doing any work, and it would not be difficult by means of the air pipes in the flues to take up much of this waste heat and send it into the boiler again in the manner described. In such a case it was easy to understand how an apparent economy would be obtained by the plan of air injection; but the question to consider was the economy that would be effected in applying the plan to a good boiler, where there was but little heat escaping as waste that could be taken up by the air pipes.

Mr. WARSOP replied that the boilers upon which the very careful experiments described in the paper had been made were both of them considered very good boilers. The Nottingham boiler was a Cornish multitubular, and made steam very well; the consumption per actual horse power measured by the break was 5·53 lbs. per hour of ordinary engine coal when working with steam alone, and 3·40 lbs. when the air injection was applied, showing a saving of 38 per cent. due to the air injection. With the London boiler shown in Fig. 4 the consumption per actual horse power per hour was 5·88 lbs. with steam alone, and 4·72 lbs. with the air injection, showing a saving of 20 per cent.

Mr. EATON said that in the construction of the experimental boiler shown in Fig. 4 directions had been given that it should be made in the best possible way in every respect, so as to give every advantage to steam, in order that it might be correctly ascertained what amount of gain really resulted from the application of the air injection in a good boiler. The result of these experiments was a gain of 33 per cent. in the work done by a given weight of fuel with the air injection when the engine was running quickly, and 24 per cent. when running more slowly; these amounts would both have been greater, had it not been that the piston of the air cylinder was not a good fit and allowed a leakage of air.

Mr. J. TOMLINSON remarked that he had not seen any of the boilers to which the air injection had been applied, but from the drawings exhibited he was inclined to think much of the economy attributed to the air injection might be secured by better constructed flues, arranged so as to allow less of the heat to pass away as waste. He did not understand what became of the deposit that was contained in the water supplied to the boilers, as it was not found in the form of incrustation in the boilers, and could not have passed through the cylinders with the steam, because it had been stated that there were no signs of wear upon the cylinder and piston surfaces such as would have been occasioned by the presence of solid particles in the steam. In marine boilers working with surface condensers it was true that there was a complete absence of scale; but in that case there was no further supply of new water bringing in additional saline matter to form incrustation, and the pure water returned from the surface condensers could not cause any deposit in the boilers. In regard to the experiment which had been made with artificial salt water of double the strength of sea water, it must be borne in mind that the actual degree of saturation reached in ordinary marine boilers working without surface condensation was considerably higher, amounting at times to from 3 to 3½ times the saltness of sea water.

Mr. WARSOP said that in the Nottingham boiler from which the specimen of foul water exhibited had been taken after working for three months without blowing off, a deposit like flour was found at the bottom, after the boiler had been allowed to stand a night and when the water had been all emptied out of the boiler, which was done by a hand pump on account of there being no blow-off cock at the bottom of the boiler. The quantity that was collected of this deposit was only about one gallon in the large boiler shown in

Fig. 1, of 20 feet length and 6 feet diameter, after four months' working.

Mr. EATON observed that in the Nottingham water the prevailing ingredient was carbonate of lime, and the carbonic acid gas introduced into the boiler in the air injection appeared to have the effect of dissolving this to such an extent, that when the water was run off after a long time of working without blowing-off there was only left at the bottom of the boiler the small amount of sediment that had been mentioned. In the boiler at Chatham, where the prevailing ingredient in the water was chalk, the sediment found after running the water off was a substance resembling brown snuff; and in the boiler at Stratford the sediment was of the same character but rather lighter in colour. In the case of the "Fox" steamer, there had been a blow-off from the scum-cock at frequent intervals, which would account for a certain quantity of the saline deposit being got rid of. Without the air injection there was no doubt that a thick solid scale would have been formed upon the boiler plates in all these cases, judging from the experience of the boilers not supplied with air injection but working under the same circumstances in all other respects. With the air injection the sediment in the water was retained in a state of suspension while the boilers were at work, without becoming deposited upon the plates in any part; and it was only when the boilers were allowed to stand for a time that this sediment settled down to the bottom, forming then not a hard scale but a sort of sludge, which was easily removed from time to time by blowing-off in the ordinary way.

Mr. H. WOODS enquired what was found to be the amount of deposit produced in the vertical boiler shown in Fig. 3 when working without the air injection.

Mr. EATON replied that that boiler had not been tried long enough without the air to allow of the formation of any appreciable scale; but Messrs. Thackeray's boiler that had worked without the air injection previous to the boiler shown in Fig. 1 had required attention ordinarily about once in every six weeks to remove the scale formed upon the plates.

Mr. H. Woods said he had been led to make the enquiry because he had himself put up a couple of vertical boilers very like that shown in Fig. 3, and had been agreeably surprised to find that after working five or six weeks there was only the thinnest possible deposit upon the plates; the sediment that collected at the bottom of the boilers was blown off regularly at the time of starting the engine. These boilers had now been working for some years, and had continued particularly clean, which he considered to arise from the very rapid evaporation in the tubes causing so active a circulation of the water, that the deposit was prevented from settling down quietly and forming a scale.

Mr. E. B. Marten said that in examining the Nottingham boiler working with the air injection, Fig. 1, he had enquired what became of the sediment from the water; and he found that the boiler was blown off at intervals into an adjacent drain, but as it was situated below the level of the drain, the water could only be blown off under steam pressure, and therefore the sediment would be all blown out, and by the time the boiler was emptied of water there would not be any sediment remaining in it. In this way the absence of sediment in that boiler after blowing off would be satisfactorily accounted for.

The Chairman enquired how long any of the iron heating pipes in the flues had been in constant work, and how they were found to stand.

Mr. Warsop replied that the heating pipes seemed to stand very well, being away from the direct action of the fire; it had not been necessary to replace any of them, and he believed they all continued as good now as when new. No leakage of air occurred in the heating pipes; he had tried this by putting a pressure gauge on each end of the pipes, which would have shown a difference of pressure between the two ends if any leakage had existed. In the Nottingham boiler shown in Fig. 1 the heating pipes had now been twelve months in constant use. In one case the small holes in the air delivery pipe inside the boiler had become choked up, causing extra pressure against the air-pump; a blow-off cock upon the air delivery pipe was however now adopted, by which means any sediment that might collect in the pipe during the night was blown out before starting work in the morning, and the air holes were found to keep permanently clear.

Mr. F. J. Bramwell enquired what proportion of air and steam was considered the best.

Mr. Warsop replied that the proportion preferred was 12 per cent. of air; that is, the volume of air when compressed to the boiler pressure but at the temperature of the atmosphere should be 12 per cent. of the volume of steam taken into the steam cylinder at the point of cut-off. This required that the capacity of the air-compressing cylinder, when single-acting and worked direct from the engine, should be about one quarter of the capacity of the steam cylinder; in general however he employed a separate donkey engine for supplying the air injection to the boiler.

The Chairman remarked that the subject of the paper was a very interesting one, both on account of the theoretical questions involved, and also in consequence of the practical results that had been arrived at, which seemed to be of a decidedly favourable character. The main question that presented itself in regard to the use of the air injection was, what was the cause of the advantages ascribed to it. These advantages were of two kinds:—first, the advantage in the boiler of preventing sediment and preventing priming by the injection of heated air into the water; and secondly, the advantage in the engine of getting more work done by a given volume of the mixed steam and air than would be performed by an equal volume of steam alone at the same pressure.

With regard to the advantage in the boiler, consequent upon the injection of divided currents of heated air into the water, he thought there was reason to anticipate a marked effect from such a process; for each bubble of heated air rising through the mass of hot water would naturally become saturated with steam by its contact with the water, increasing in volume many times, and would thus relieve the evaporating surface of the boiler of part of the work it would otherwise have to perform. Moreover in ordinary boilers, the steam being generated only in contact with the evaporating surfaces of the boiler plates and tubes, each bubble of steam at the moment of its generation left behind it a liberated particle of solid matter, which had previously been contained in the water; and this being liberated in immediate contact with the boiler surface, it was natural and probable that it should attach itself at once to that surface in the form of a solid incrustation. If however the required evaporation in a boiler could be produced otherwise than in contact with the plates, it appeared likely that the sediment in the water would form itself into mud composed of an aggregation of separate small particles; and from the facts brought forwards in the paper this seemed to be the action that really took place with the injection of the heated air. With regard to priming, an interesting point to ascertain in a boiler working with the air injection would be the temperature of the water with reference to the working pressure of the mixed steam and air: because when two gases co-existed in the same space, each exerted its pressure independently of the other, and therefore it seemed reasonable to infer that the temperature of the water would be lower than the temperature corresponding to the pressure in the boiler, in the proportion of the original pressure of the steam alone to the actual pressure of the combined steam and air in the boiler. Thus supposing that the steam in the boiler were at a total pressure of three atmospheres, the water being at the corresponding temperature of 275° Fahr., and that an equal volume of air at atmospheric pressure were compressed and forced into the boiler, the compressed air would expand again to atmospheric pressure in the boiler during the transit of the air bubbles through the heated water, and each bubble of air would take up steam by vaporisation until the point of saturation was reached. The pressure of the mixed steam and air in the boiler would then be four atmospheres, while the temperature of the water would correspond to the density of the steam irrespective of the air present, and would consequently remain that corresponding to a pressure of only three atmospheres, the atmosphere of air permeating the whole steam space in equilibrium, in accordance with the law of the mutual diffusion of gases. It would be interesting to observe whether this were really the fact; and if it were so, he thought it would explain the circumstance which had been mentioned in the paper, that the moment the air was turned off violent ebullition and priming took place. For as soon as the air was turned off, the mixture of air and steam over the water in the boiler would no longer be replenished by a similar mixture of gases; and the temperature of the water being below that corresponding to the pressure of the mixed air and steam, a sudden collapse of the steam would necessarily take place; and as a consequence the engine would require more steam, the throttle-valve would open wide, and the larger volume of steam suddenly called for would of itself naturally induce priming, independently of the further circumstance that the liberation of the steam from the water would no longer be facilitated by the passage of bubbles of heated air through the mass of the water.

In reference to the other question—why the mixture of steam and air should do more duty in the engine than an equal volume of steam alone at the same pressure—he did not think this could be because the air-compressing engine which was united with the steam engine was more economical than the steam engine itself. On the contrary, mere air engines, wherever they had been tried, had not given such favourable results as good steam engines; and there were theoretical reasons why they could not give better results than a proper steam engine. It had however occurred to him as an explanation which might be suggested of the economy found to result from the use of mixed steam and air in the engine, that the presence of air in the steam cylinder would certainly prevent the condensation of steam against the sides of the cylinder: and the loss from this cause he believed to be much greater than was usually supposed. If the cylinder was uncovered, the loss by condensation was very great, and was shown by the form of the indicator diagrams taken from such engines; and even when the cylinder was carefully clothed, there was a considerable condensation from the high-pressure steam coming in contact with surfaces that had been cooled by previous exposure to the condenser or to the exhaust steam at atmospheric pressure. This condensation he believed took place even when the steam cylinder was thoroughly steam-jacketted all round and at the ends, although to a much less extent, and in that case it arose from the slow conducting power of the thick metal sides of the cylinder allowing the inner surface to continue considerably cooler than the outer surface heated by the steam in the jacket; and though the steam thus condensed in the cylinder was afterwards evaporated again in the latter part of the stroke, yet its mechanical effect was almost entirely lost. The presence of air mixed with the steam, it appeared to him, would have the effect of preventing this condensation from taking place after the first moment of contact of the steam with the cool metal, because at that moment the condensation of the particles of steam which first touched the cool metal would leave a lining of air in contact with the metal, consisting of the portion of air that had been mixed with the steam before its condensation; and a veil composed of the non-condensible and non-conducting portion of the mixed gases would thus remain to protect the rest of the steam in the cylinder from contact with the cool metal surfaces, and would thereby prevent further loss from condensation. He believed this was a point of considerable importance in favour of the use of the combined steam and air in an engine with unprotected cylinders. The application of the same plan to a condensing engine was one that he had not been acquainted with previously; and from the statements which had been given it appeared that the introduction of so large a quantity of air with the steam had not been found to prevent the formation of a tolerable vacuum.

The use of the air injection was a subject which he hoped would be more fully investigated; and from the perseverance which had been shown in working it out thus far there was reason to expect the plan would be developed to a still further extent. He moved a vote of thanks to Mr. Eaton and Mr. Warsop for the paper, which was passed.

The following paper was then read:—

DESCRIPTION OF A WIRE-ROPE BRIDGE AT THE LANDORE STEEL WORKS FOR CONVEYING MATERIALS ACROSS A NAVIGABLE STREAM.

BY MR. WILLIAM HACKNEY, OF SWANSEA.

In carrying out recently an extension of the Landore Siemens-Steel Works near Swansea, it became necessary to devise some inexpensive means of conveying the spoil removed from the excavations, across the river Tawe which runs by the side of the works, and depositing it on the low marshy ground at the other side. The river is a hundred feet wide at mean high-water level, and is navigable at spring tides for vessels of 200 to 300 tons burden; and it was therefore a necessary condition that any bridge thrown across the stream should be arranged so as not to interfere with the passage of vessels.

The construction of the moveable Wire-Rope Bridge designed by the writer to meet these requirements is shown in Figs. 1 and 2, Plate 72, which represent a general elevation and plan of the bridge. It is constructed of two steel wire ropes A A, 1 inch diameter, strained tightly across the river, 6 feet apart, between timber framings B and C on each bank, from which stays are carried down to anchorages D D in the ground. These ropes form in effect a double line of rails, and on them travel two runners or carriages E and F, one on each rope, from which the small ballast trucks are hung by chains and hooked clips. The runners are made of boiler plate, and are carried each upon a pair of 10 inch cast-iron wheels; and they are connected together by a light endless wire cord G passing round pulleys fixed in the two end framings B and C, Figs. 3 and 7, the cord being led into the groove of the pulleys by bell-mouthed guides, as shown at I I in Figs. 6 and 7, Plate 74. As the yard level of the works is 18 feet higher than the platform on which the trucks land at the other side of the river, the ropes are inclined at a mean slope of about 1 in 9, down which the trucks run easily by their own weight.

To send a full truck of earth or slag across, it is run against a blocking frame H at the upper end, as shown in Fig. 3, Plate 73, and is hooked on the runner E, and an empty truck is at the same time hooked on the other runner F at the lower end. A stop-block in front of the loaded truck is then raised, and the truck runs down by its own weight along the rope, drawing up the empty truck. The speed is regulated by a break fixed on the shaft of the upper pulley, Fig. 3, and worked by a cord from the blocking frame H. The motion is however very regular, and but little break power is required, as the incline down which the loaded truck runs decreases from the start to the finish, owing to the deflection of the wire rope under the weight, the steepest inclination being close to the upper bank; while at the same time the incline up which the empty truck is drawn increases, and its retarding effect becomes proportionately greater. The empty truck is unhooked from the runner on its arrival at the upper end, and is replaced by a full one; while a second empty truck is hooked on the other runner at the lower end in the place of the full truck just sent down. The stop-block in front of the full truck is then raised, and the truck runs down the rope, drawing up an empty truck as before. The length run along the rope is 165 feet, and the time occupied in traversing it is about 14 seconds, giving a mean speed of 8 miles an hour.

The arrangement for preventing the bridge interfering in any way with the passage of vessels is as follows. The upper framing B, Fig. 1, supporting the wire ropes, is carried on a four-wheeled truck running on rails, as shown to a larger scale in Figs. 3 and 4, Plate 73; and is arranged so that on unhooking the chains K K from the anchorages, and slacking the friction break of the crab-winch L, the whole framing is drawn forwards by the weight of the ropes into the position shown dotted at M; both the fixed and the running ropes then sink to the bottom of the river, as shown by the dotted line in Fig. 1, leaving the navigation entirely free. The bridge can be let down in this way by two men from its working position within two minutes from the time that a vessel is seen to be approaching, and can be pulled up again ready for work in ten minutes more, so that the whole time of the stoppage to let a vessel pass is considerably under twenty minutes. As vessels seldom pass up or down oftener than once or twice a week, the interruption of work to let them go by is very slight. To avoid risk of accident, the bridge is always let down at night or when it is not in use. The grooves alongside the rails on which the moveable framing B runs are covered during working by T iron guards, to admit of running the ballast trucks across them.

The anchorages D D, Figs. 1 and 2, are formed of two old wrought-iron tanks buried in the ground. At the lower end of the bridge each rope is connected directly to the anchorage, by a tie rod fitted with an adjusting swivel and a right-and-left-handed screw. At the upper end of the bridge the tie rods N from the anchorage, Figs. 3 and 4, are connected at the ground level to two strong hooks J J fitted with right-and-left-handed tightening screws P. These hooks engage in the end links of the chains K, and are kept from slipping out of the links by small cross pins. The chains K are fastened by shackles to other chains attached to the upper framing B; the position of the shackles is adjusted so that when the ropes are drawn up tight the strain is thrown fairly on the centre of the framing B, and there is no tendency to racking it or to an unequal distribution of the weight on the fore and hind wheels. A distance piece R, Fig. 2, is slipped loosely into the links of the chains K close to the shackles, to keep them at the proper distance apart, and to prevent any racking sideways when the weight in working comes alternately first on the one rope and then on the other. The lower ends of the chains K are supported by a cross bar S, Fig. 2, which holds them up off the ground until the hooks J are attached to them.

When the bridge is to be raised, it is first drawn up as tight as possible by the double-purchase crab-winch L, Fig. 3, Plate 73; the hooks J are then dropped into the end links of the chains K, and the remaining slack of the wire ropes is taken up by a few turns of the tightening screws P. The crab-winch is thus relieved from all strain during the working of the bridge, and the pull on each rope is taken directly in a vertical plane from the one anchorage to the other. The crab-winch is tied back to the rods leading down to the main anchorage.

The ends of the main wire ropes are fixed into wrought-iron blocks, which are connected by hinged shackles to the tops of the framings B and C, Fig. 1; the blocks and shackles are shown to a larger scale in Figs. 8 to 10, Plate 74. One shackle is fitted with adjusting screws, as shown in Fig. 8, to allow of adjusting the relative length of the ropes, so that they may be drawn up equally tight; the other three shackles, as shown in Fig. 9, have no provision for adjustment.

The mode of fixing the ends of the ropes into the wrought-iron blocks T T, as shown in Figs. 8 and 9, is adopted from the practice of American engineers, and has proved very satisfactory. An iron ferrule is first closed round the rope near the end, and the projecting end of the rope being passed through a conical hole in the block, the wires are carefully opened out in the form of a brush, and well oiled. A stout conical pin is then placed in the centre of the brush, and smaller pins are driven in round it, taking care to separate the wires as much as possible, and to insert the pins uniformly between them. The pins are driven in flush with the top of the block and as tight as possible, until no more can be got in; and the projecting ends of the wires are then bent over in succession across the centre, and the whole is leaded over and dressed off with the chisel, as shown in the drawing. This fastening for the ends of wire ropes is stated to be capable of bearing the full breaking strain of the rope without yielding, and it is easily made and appears to be of general utility.

In working out the details of the bridge, a difficulty was at first experienced in contriving some ready mode of hooking on and unhooking the trucks without requiring any slack in the suspending chains. This has been effected by providing each runner with four suspending hooks or clips, shown in Fig. 11, Plate 74, which are slipped into eyes, one at each corner of the truck, and secured by hinged guards and rings. Each hook is at the end of a short chain, and the truck is suspended at the required height by hooking up these chains accordingly upon the hooks on the runners. The trucks, whether running up or down, are hung always higher in front than at the back, in order that they may take the ground easily in landing at either end. This is arranged by reversing the lengths of the sling chains at each end after a truck is landed, before the return truck is hooked on in its place. The trucks land on curved wrought-iron plates, the elasticity of which takes off most of the shock of landing; and at the upper end, where they pass through the blocking frame H, they are guided in by side guards U U of iron plate, Figs. 3 and 4.

The blocking frame H, Fig. 3, of which the inside elevation is shown in Fig. 5, is made with two sliding stop-blocks V V, for stopping the full trucks by their projecting buffers whilst they are being hooked on the runners. To send a truck across, the stop-block is then raised a few inches by the lever, as shown on the left-hand side of Fig. 5, so as to clear the buffers of the truck, which starts at once by its weight along the rope. The guides of the stop-blocks are arranged so that a truck on landing will lift the block and pass in under it; but in practice the blocks are kept hooked up after a truck is sent off, until the return empty truck has passed in.

The average load sent across the bridge at a time is about 17 cwts., including the weight of the truck and runner; and under this load the rope deflects about 5 feet from a straight line when the weight is in the centre, as shown in Fig. 1. The strain brought by this load upon the ropes and fastenings is about 9 tons, but this varies considerably according to the tightness to which the ropes are stretched. About 30 trucks may be sent over in an hour, or 300 per day of ten hours; and taking the net load of each truck at 10 cwts., this gives a capacity of 150 tons per day: a small quantity comparatively, but one which might be readily increased by adding to the strength of the ropes and fastenings, so that loads of two, four, or more tons might be sent over at a time.

The bridge as erected is indeed scarcely more than a working model, and the writer has given this description of it rather as an example of cheap temporary construction than as a finished design. It has however worked very satisfactorily, and has proved quite sufficient for the purpose for which it was required.

In adapting the same form of bridge to other circumstances, many modifications might be introduced. In a larger bridge turntables might be provided at the ends, to facilitate the shunting of the heavy trucks; and it might be found desirable to run the trucks upon platforms hung from the ropes, and fitted with springs to prevent any shock on landing, instead of slinging them directly by clips and chains. The weight of the ropes might be counterbalanced, to equalise the strain throughout the traverse of the moveable framing in hauling them up, so that they might be hauled up or let down by one man. The anchorage hooks should also be counterbalanced in a larger bridge, as they would otherwise be too heavy for convenient handling.

Again, if the loads were to be sent across a river on a level, or from a lower to a higher level, it would be necessary for one or other of the pulleys of the endless running cord to be turned by power against the weight of the load. By mounting the engine employed for this purpose upon the moveable framing B, Fig. 1, it might be conveniently used also for lowering and raising the bridge.

With such modifications the plan of bridge described in the present paper may perhaps be found useful in cases in which building materials or other loads have to be sent across navigable rivers, in situations where a fixed low-level bridge is inadmissible.

Mr. Hackney said the bridge had now been in use five months and had answered its purpose very well. The only parts that had required repair had been the small carrying wheels of the runners on the wire ropes, which had been found after about three months' work to be deeply grooved in a spiral form by the strands of the ropes. When these grooves in the wheels had worn deep they caused more friction on the ropes; and the wheels had therefore been taken off and turned down in the lathe to take out the marks, and then put to work again on the runners. The cost of the bridge, taking the portion above ground and excluding the anchorages and floor plates, had been from £110 to £115; and allowing for the floor plates, and for the old iron tanks used for anchorages, which happened to be in the yard, the total cost would be about £150.

The Chairman enquired what had been found to be the cost of the bridge per ton of material transported.

Mr. Hackney replied that the cost of sending the loaded trucks over the bridge, tipping them at the other side, and bringing the empty trucks back, was about 2*d.* per ton; the men were paid 1*d.* per truck, and each truck contained from 10 to 12 cwts., the number of trucks sent over being about 300 per day. To this cost would have to be added a charge for interest on outlay and for wear and tear; but the latter would be so insignificant that it might be neglected, as the only parts in which wear had occurred had been the wheels of the runners, and the rest of the bridge had not yet shown any signs of wear. The number of men employed for working the bridge was two at each end for receiving the trucks and sending them off, and at the lower end two more men were employed to tip the full trucks and bring them back to the bridge and to keep the tip in order, making six men altogether.

The Chairman enquired whether it had ever happened that the trucks had stuck midway in crossing the bridge, or that the runners had got off the wire ropes.

Mr. Hackney replied that the trucks had never stuck in crossing the bridge; but if a truck was sent over only half loaded, or filled with a light load, such as ashes, it would not quite land itself at the end, and had to be pulled up a little by hauling in the wire cord by hand; with any load above 7 cwts. however the trucks landed themselves perfectly well. At first there had been no side guards to guide the trucks in landing at the upper end, and the trucks swayed a little and had caught sometimes against the blocking frames at the upper end; but this had since been obviated by adding side guards to guide the trucks into the centre of the blocking frames, and the trucks now landed without ever catching against anything. No instance had occurred of either of the runners getting off the wire rope.

Mr. G. FOWLER thought that in mining practice that kind of light wire-rope railway for carrying spoil away would be very useful, as in some parts of the country timber bridges of as much as 200 to 300 yards length were frequently constructed at pit banks for the purpose. The labour charge however for working the bridge appeared to him rather heavy, which must be the case if it always took two men at the top and two at the bottom. Supposing it were not necessary to lower the bridge in order to render the stream navigable, he enquired whether that construction of bridge would be recommended in preference to a permanent timber bridge.

Mr. HACKNEY said it would be simply a question of relative first cost and cost of working. The first cost of a timber bridge would of course be greater, but then a train of wagons might be hauled across at once, which would be much cheaper in expenditure of power than taking only one wagon over at once. If however the bridge were over a deep ravine, the cost of a timber bridge would be considerably increased, and the wire-rope bridge might be found the more economical plan.

Mr. EATON enquired what would otherwise become of the material at present conveyed across the bridge, if this means of disposing of it were not available; and what would be the cost of getting rid of it without the use of the bridge.

Mr. HACKNEY replied that there was no land available for depositing the material within a mile on the same side of the stream as the works, and the ground covered by the works themselves was now quite fully occupied. Without the wire-rope bridge the only resource would have been either to cart the material away to a distance of at least a mile, which would have cost not less than 8*d.* per ton, or to build a heavier bridge over the stream; but the latter alternative was not practicable in this instance, on account of vessels passing occasionally, and any arrangement for crossing the stream was required to be such as would allow vessels to pass freely at any time.

Mr. Sampson Lloyd thought the wire-rope bridge was ingeniously designed, and well adapted for the special purpose for which it was required; and it would prove very useful for particular situations, such as that for which it had been constructed. Cases of a similar nature however were rarely met with, and permanent constructions were much more generally required, over which a great deal more weight could be conveyed in a given time than was possible with the wire-rope bridge now described.

The Chairman remarked that the plan of the wire-rope bridge was first proposed to him for the Landore Steel Works in the early part of the year by Mr. Hackney, by whom the design had been carried out entirely and in a very creditable manner; he had seen the bridge at work, and it certainly did its work with great regularity and efficiency. It was true that such a bridge would not be suitable in ordinary cases for carrying on a regular heavy traffic; but under special circumstances similar to those at the Landore works he considered it was a very useful arrangement. It was desirable for the interests of the Institution that special appliances contrived to meet particular requirements should be communicated, in order that they might be referred to at any future time by the members, who would thus be saved having to go over the same ground again. He proposed a vote of thanks to Mr. Hackney for his paper, which was passed.

The Meeting then terminated.

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COUNTERPRESSURE STEAM BREAK. *Plate 1.*

Fig. 1. *Transverse Section through smokebox, showing insertion of Injection Pipe into exhaust.*

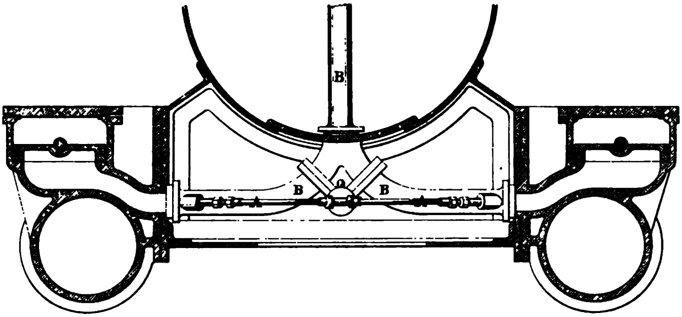
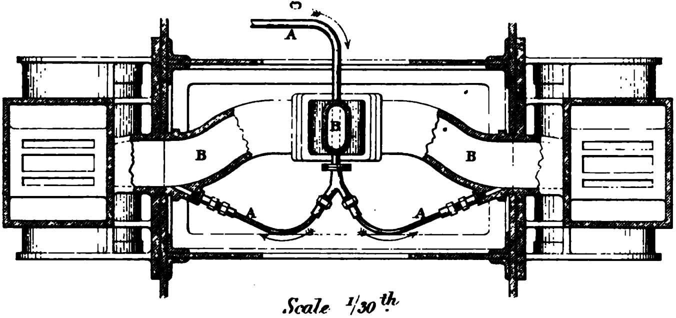


Fig. 2. *Plan.*



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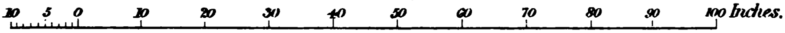

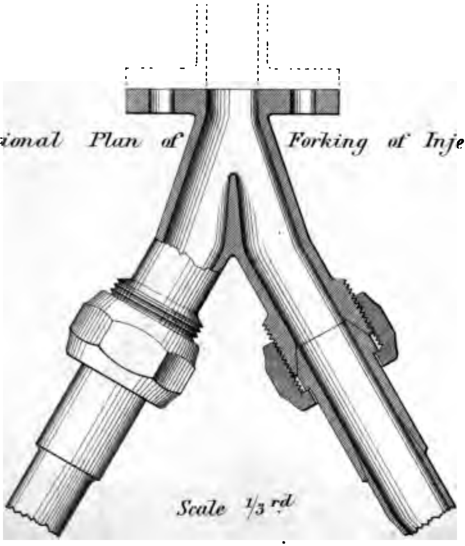

Fig. 3. *Sectional Plan of Forking of Injection Pipe.*

Scale 1/3rd

(Proceedings Inst. M.E. 1870.)

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COUNTERPRESSURE STEAM BREAK. *Plate 2.*

Fig. 4. *Arrangement of Water and Steam Injection Cocks, with Screw Reversing Gear.*

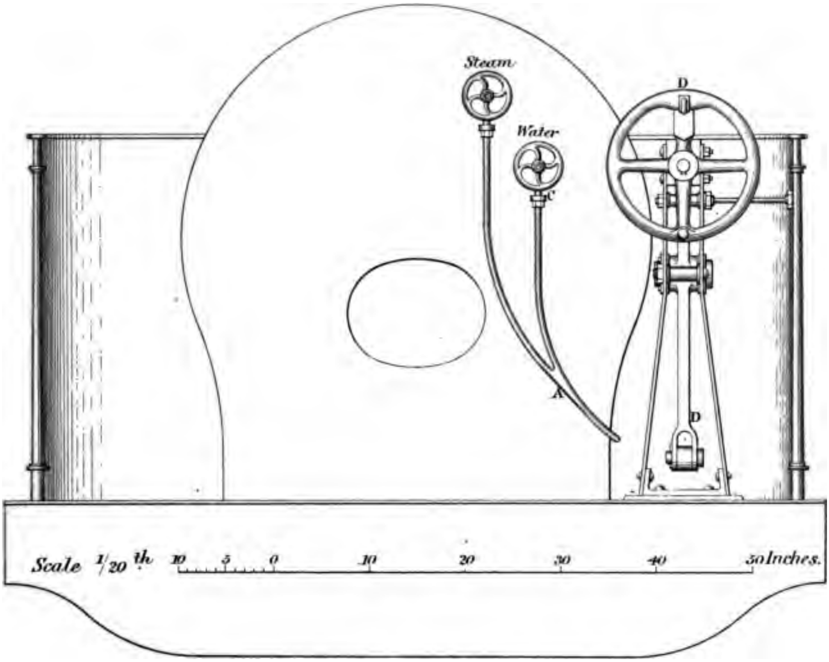
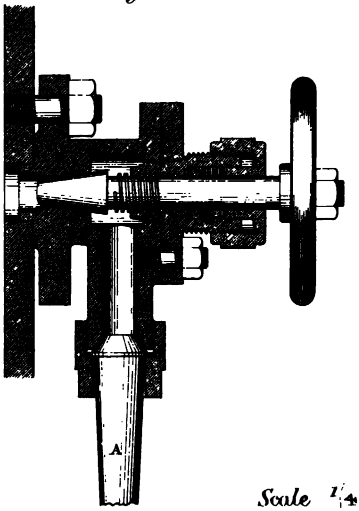


Fig. 5. *Water Injection Cock.*



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(Proceedings Inst. M.E. 1870.)

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COUNTERPRESSURE STEAM BREAK. *Plate 3.*

Diagrams illustrating Counterpressure Working.

Fig. 6. *Diagram of Ordinary Working. Cutting off at 50 per cent.*

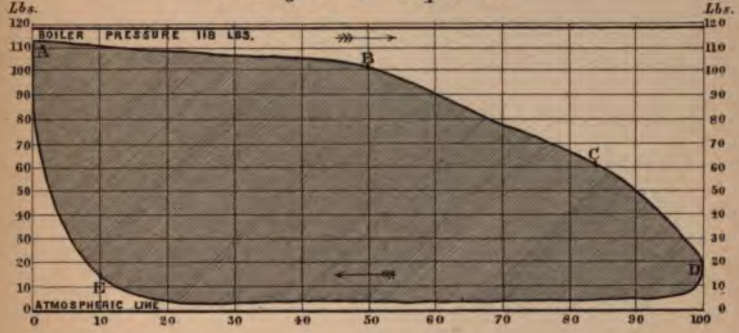


Fig. 7. *Diagram of Reversed Working. Cutting off at 50 per cent.*

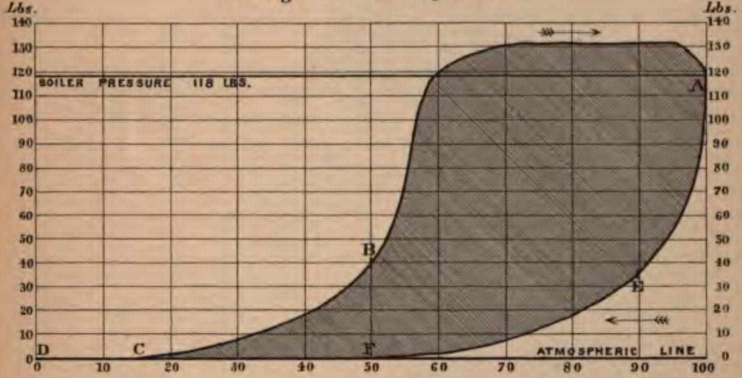
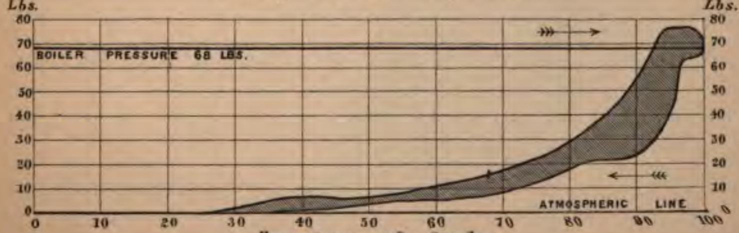


Fig. 8. *Counterpressure Diagram in Reversed Working. Cutting off at 32 per cent.*



Percentage of Stroke.

Pressure above atmosphere, lbs. per square inch.

(Proceedings Inst. M. E. 1870.)

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Diagrams illustrating Counterpressure Working.

Fig. 6. *Diagram of Ordinary Working. Cutting off at 50 per cent.*

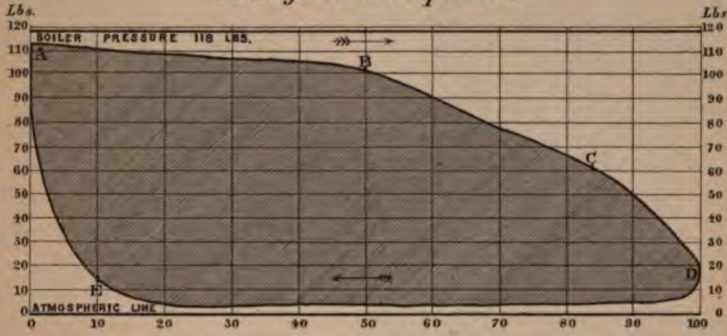


Fig. 7. *Diagram of Reversed Working. Cutting off at 50 per cent.*

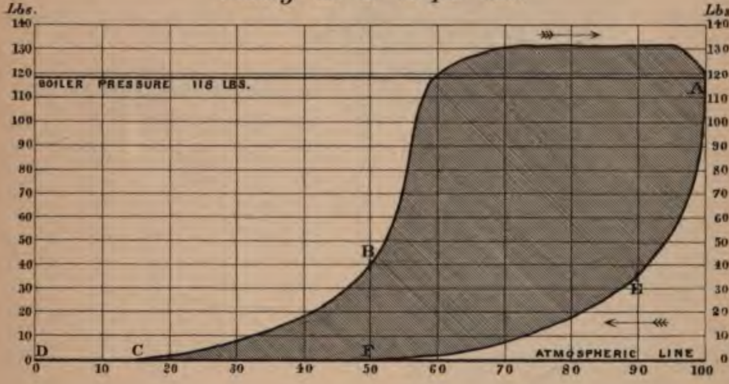
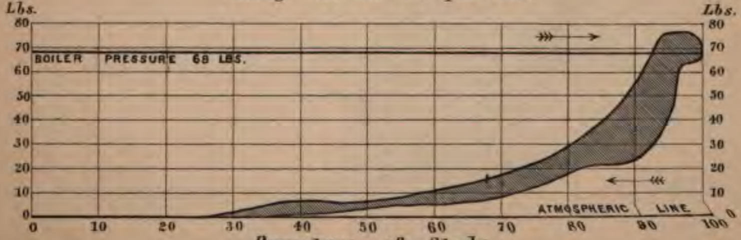


Fig. 8. *Counterpressure Diagram in Reversed Working. Cutting off at 32 per cent.*



Percentage of Stroke.

(Proceedings Inst. M. E. 1870.)

COUNTERPRESSURE STEAM BREAK. *Plate 5.*

Fig. 11. *Ordinary Diagram in forward gear,*
taken at 8 to 10 miles an hour.

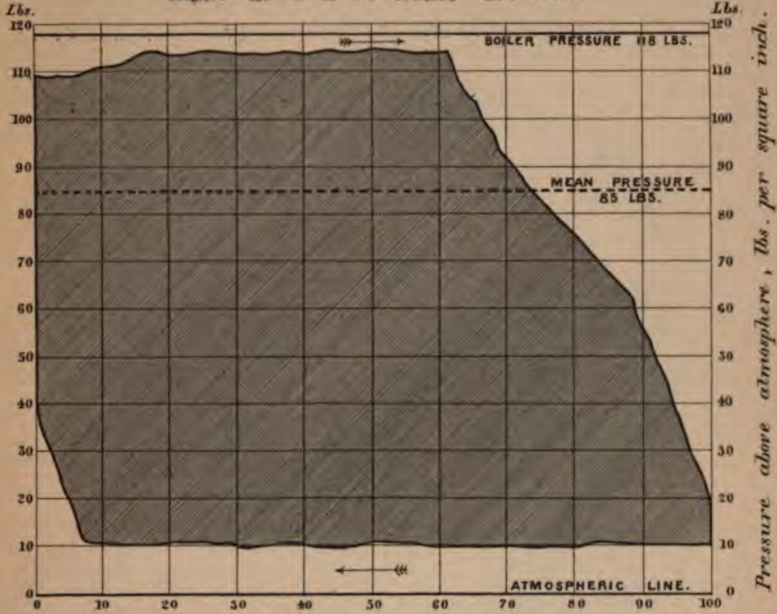


Fig. 12. *Vacuum Diagram,*
taken while running in forward gear with steam shut off,
at 8 to 10 miles an hour.

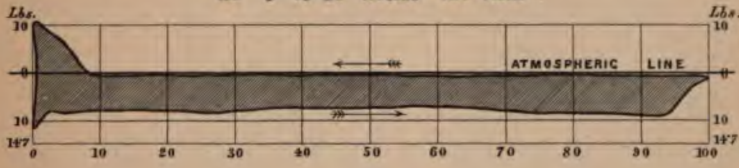
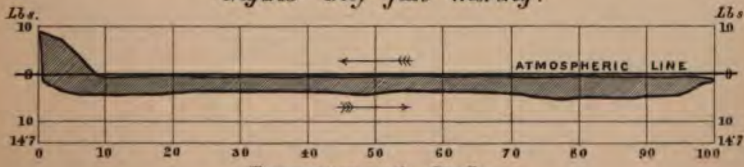


Fig. 13. *Vacuum Diagram,*
taken in forward gear with steam shut off;
engine only just moving.



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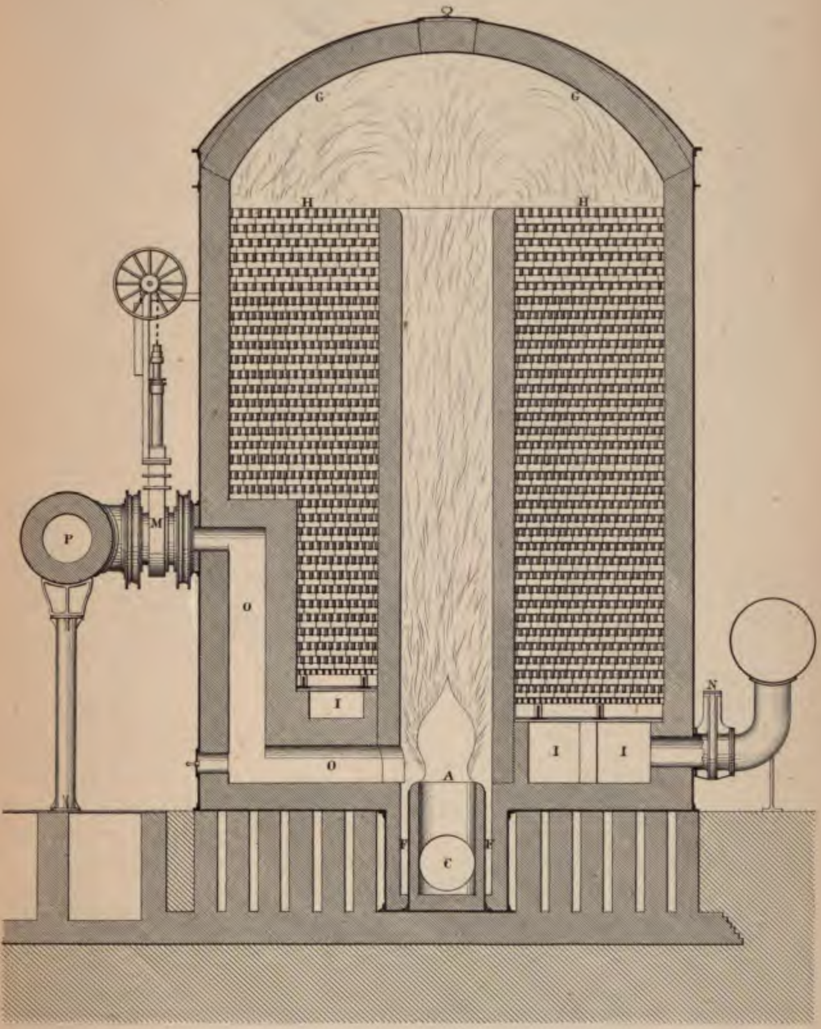
REGENERATIVE HOT-BLAST STOVES. *Plate 6.*

Improved Stoves at Ormesby Iron Works.

Fig. 1. *Vertical Section*



Scale $^1/_{120}$*th.*

10 5 0 10 20 30 *Feet.*

(Proceedings Inst. M. E. 1870.)

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REGENERATIVE HOT-BLAST STOVES.

Plate 7.

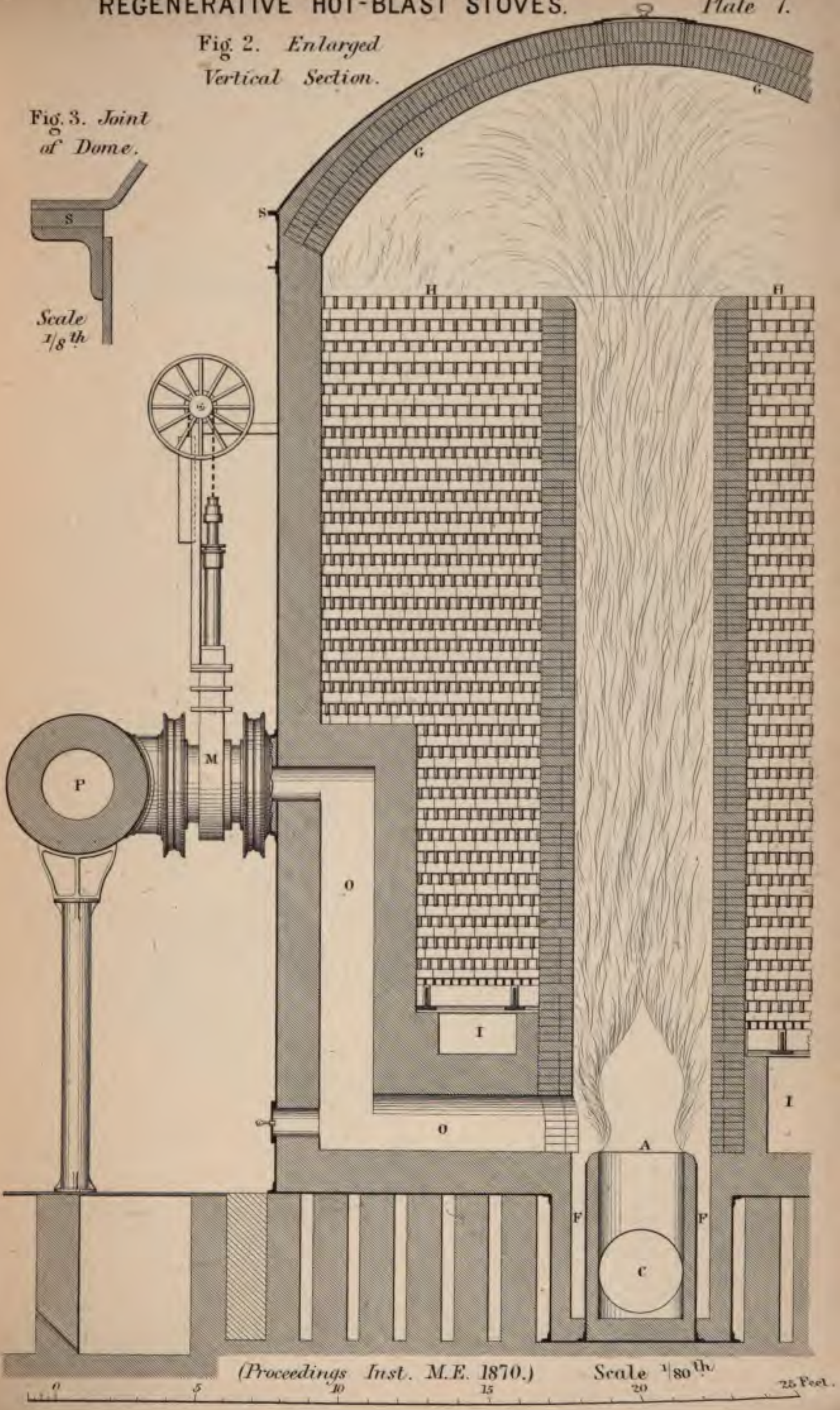

Fig. 2. *Enlarged Vertical Section.*

Fig. 3. *Joint of Dome.*

Scale $1/8^{th}$

(Proceedings Inst. M.E. 1870.) Scale $1/80^{th}$

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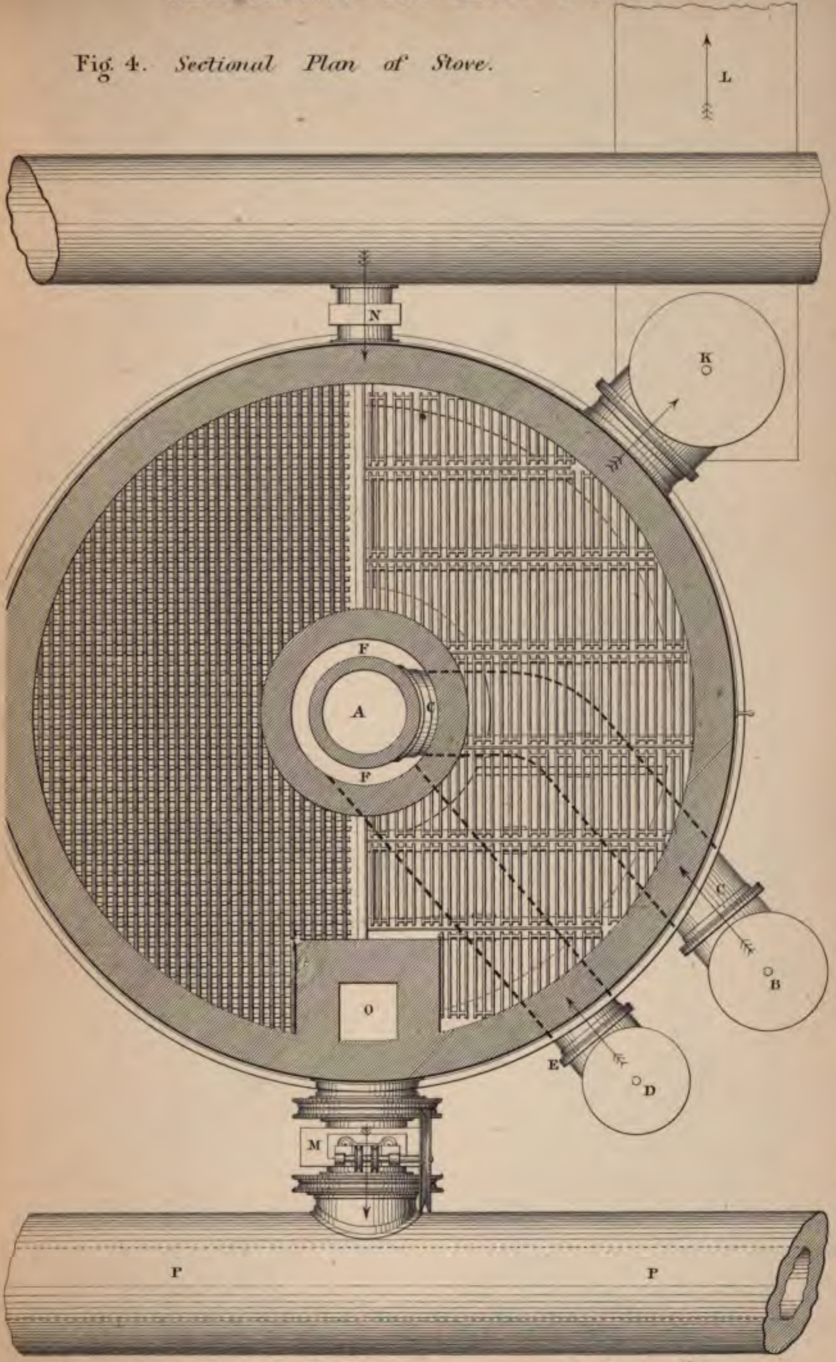
REGENERATIVE HOT-BLAST STOVES. *Plate 8.*

Fig. 4. *Sectional Plan of Stove.*



(Proceedings Inst. M. E. 1870.) *Scale* 1/80th

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REGENERATIVE HOT-BLAST STOVES. *Plate 9.*

Hot-Blast Valve.

Fig. 5. *Longitudinal Section.*

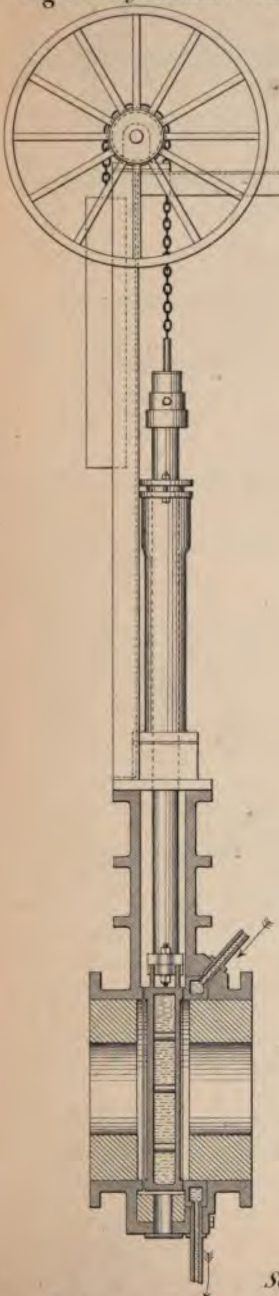
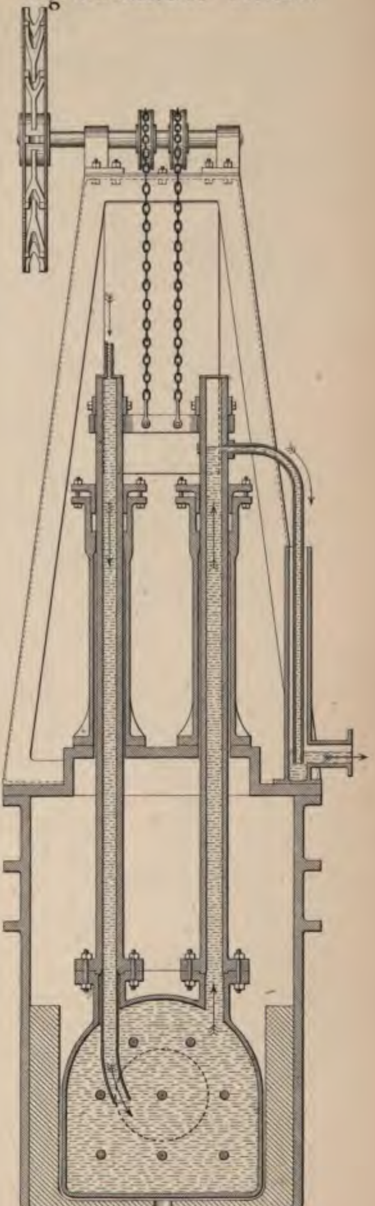


Fig. 6. *Transverse Section.*



Scale 1/30th (Proceedings Inst. M. E. 1870.)

10 5 0 10 20 30 40 50 60 70 80 90 100 Inches.

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REGENERATIVE HOT-BLAST STOVES.

Plate 10.

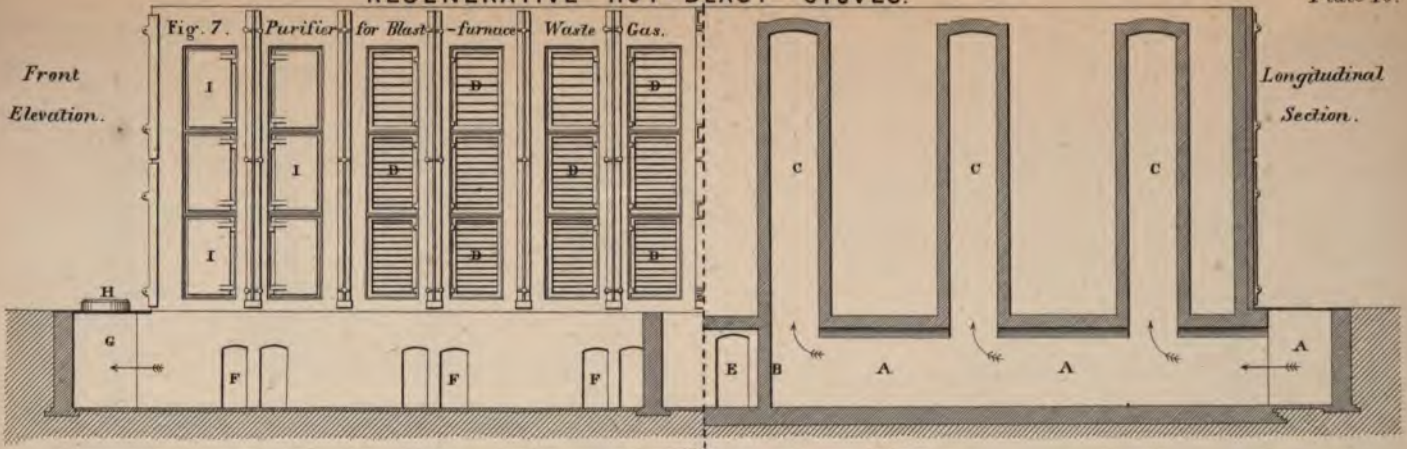
Fig. 7. Purifier for Blast-furnace Waste Gas.

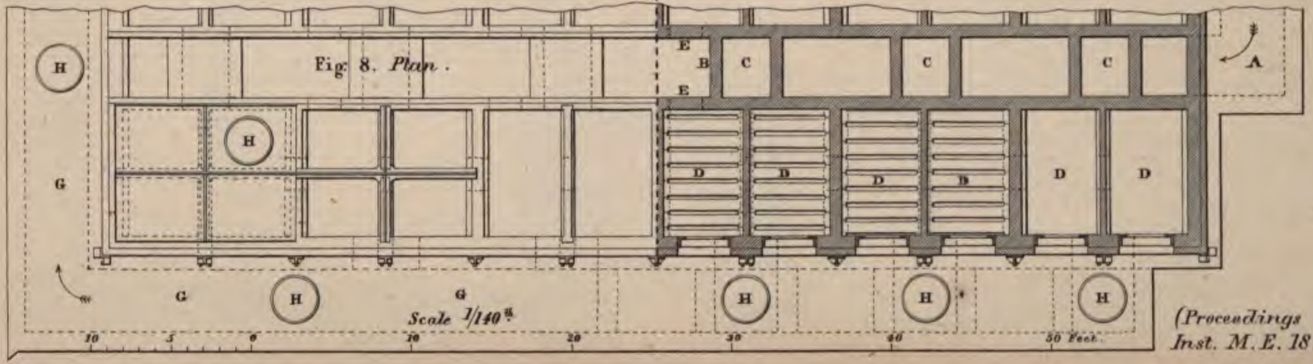
Fig. 8. Plan.

(Proceedings Inst. M. E. 1870)

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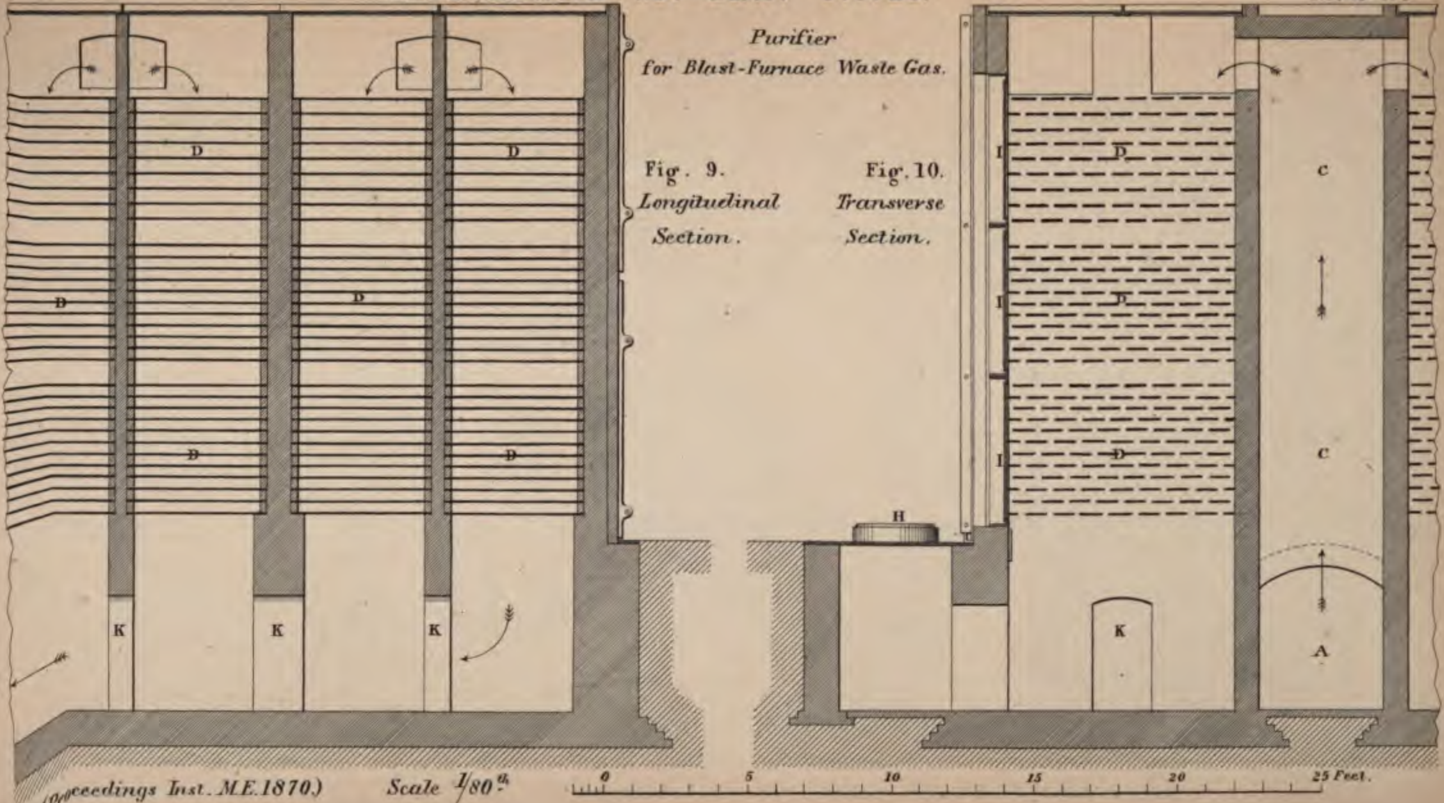
REGENERATIVE HOT-BLAST STOVES.



Purifier
for Blast-Furnace Waste Gas.

Fig. 9.
Longitudinal
Section.

Fig. 10.
Transverse
Section.

(Proceedings Inst. M.E. 1870.)

Scale 1/80th.

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REGENERATIVE HOT-BLAST STOVES. *Plate 12.*

Fig. 11. *Economy of Fuel from increased Temperature of Blast.*

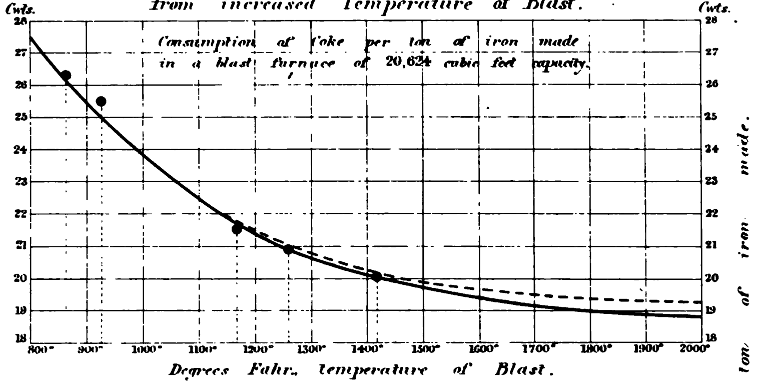


Fig. 12. *Economy of Fuel from increased Capacity of Blast Furnace.*

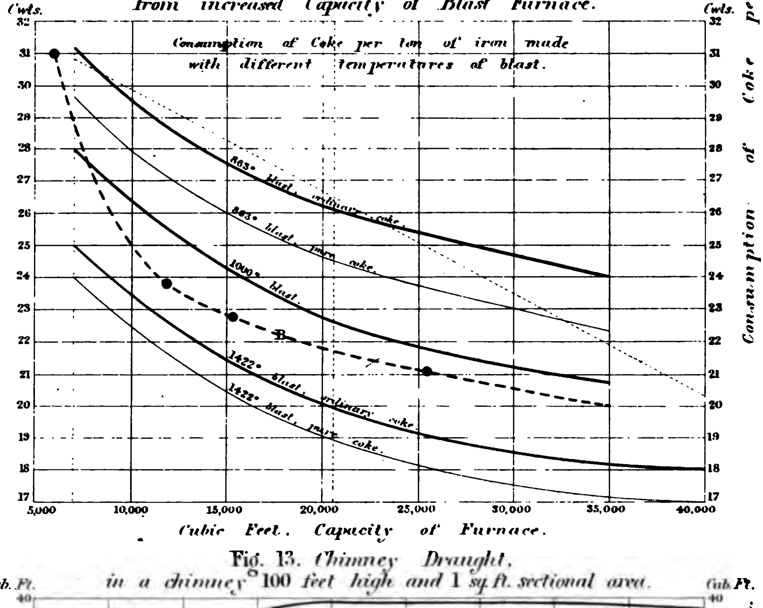
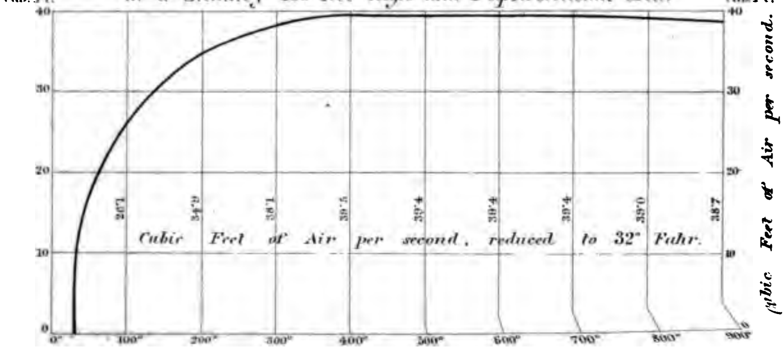


Fig. 13. *Chimney Draught, in a chimney 100 feet high and 1 sq. ft. sectional area.*



(Proceedings Inst. M.E. 1870.)

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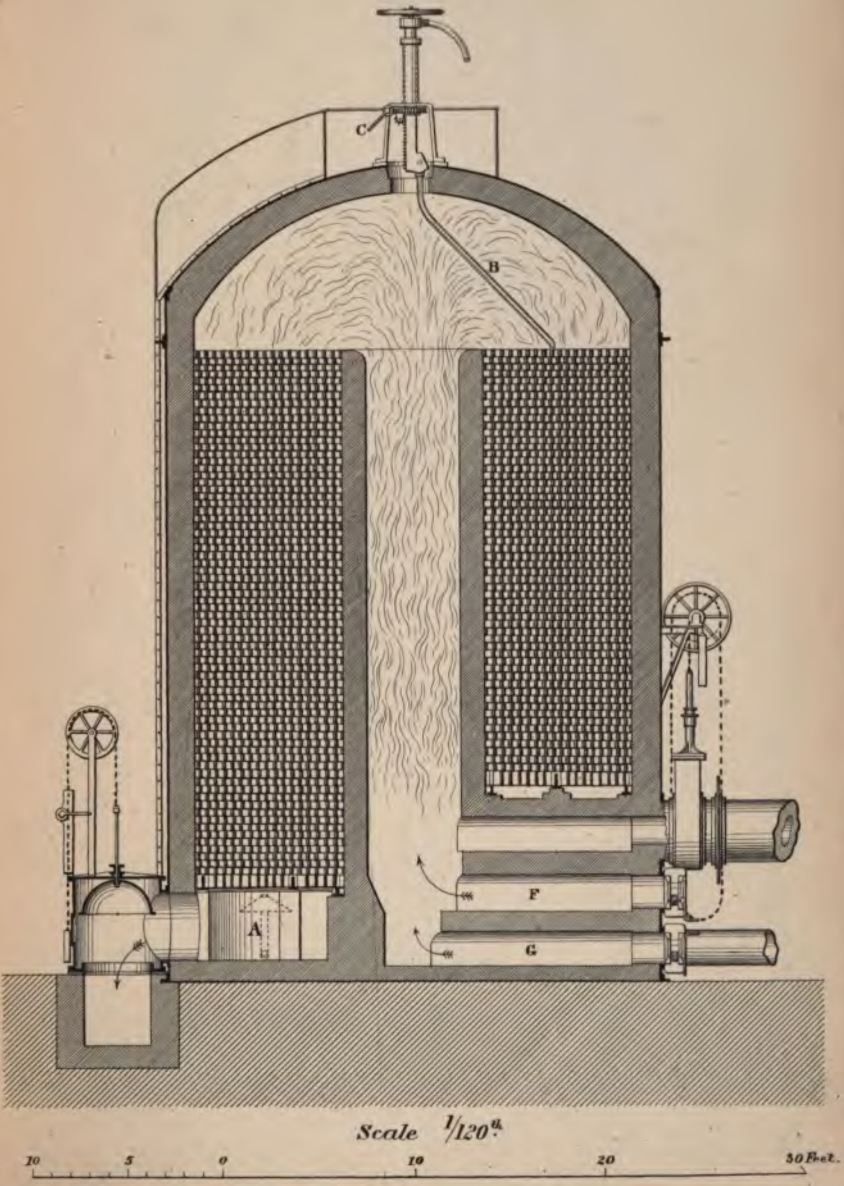
REGENERATIVE HOT-BLAST STOVES. *Plate 13.*

Improved Stove for using gas without purifying.

Fig. 14. *Vertical Section.*



(Proceedings Inst. M.E. 1870.)

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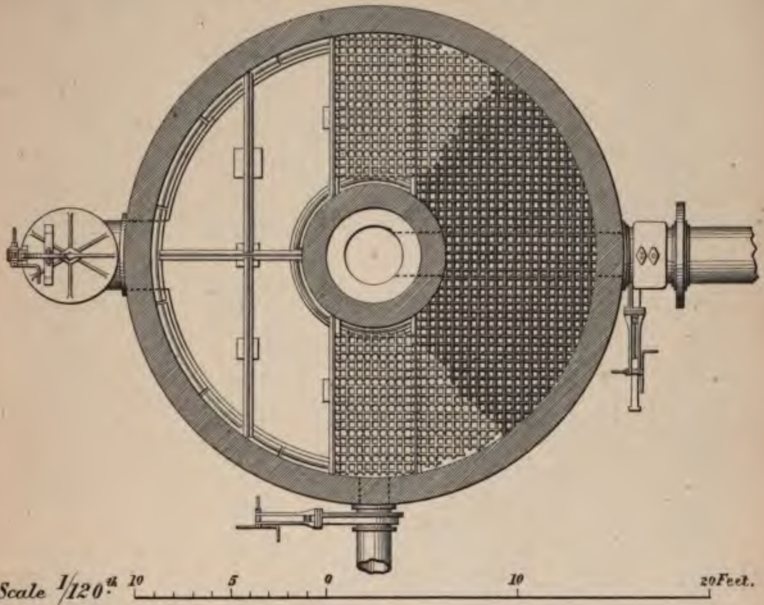
REGENERATIVE HOT-BLAST STOVES. *Plate 14.*

Improved Stove for using gas without purifying.

Fig. 15. *Sectional Plan.*



Arrangement of Bricks in Regenerator.

Fig. 16. *Plan.*

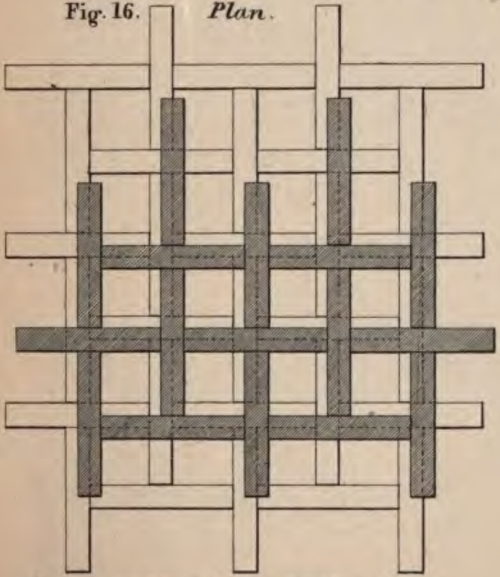
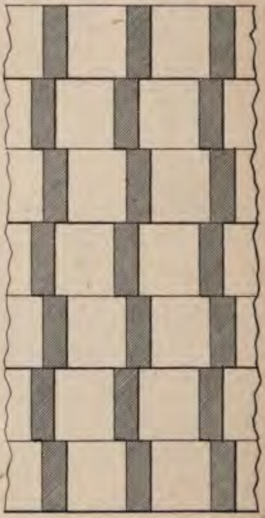


Fig. 17. *Vertical Section.*



Scale 1/12th.

(Proceedings Inst. M.E. 1870.)

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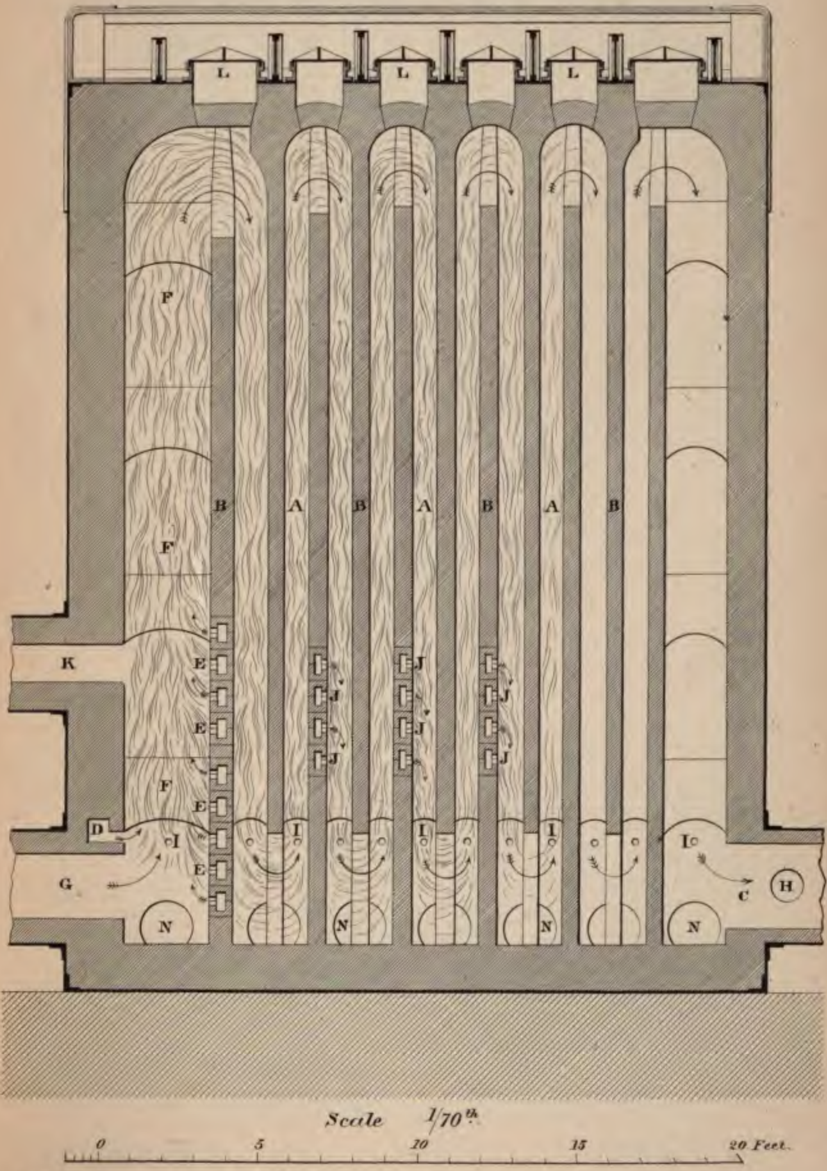
REGENERATIVE HOT-BLAST STOVES: *Plate 15.*

Regenerative Stove with Firebrick Walls at Consett Iron Works.

Fig. 18. *Vertical Section.*



(Proceedings Inst. M. E. 1870)

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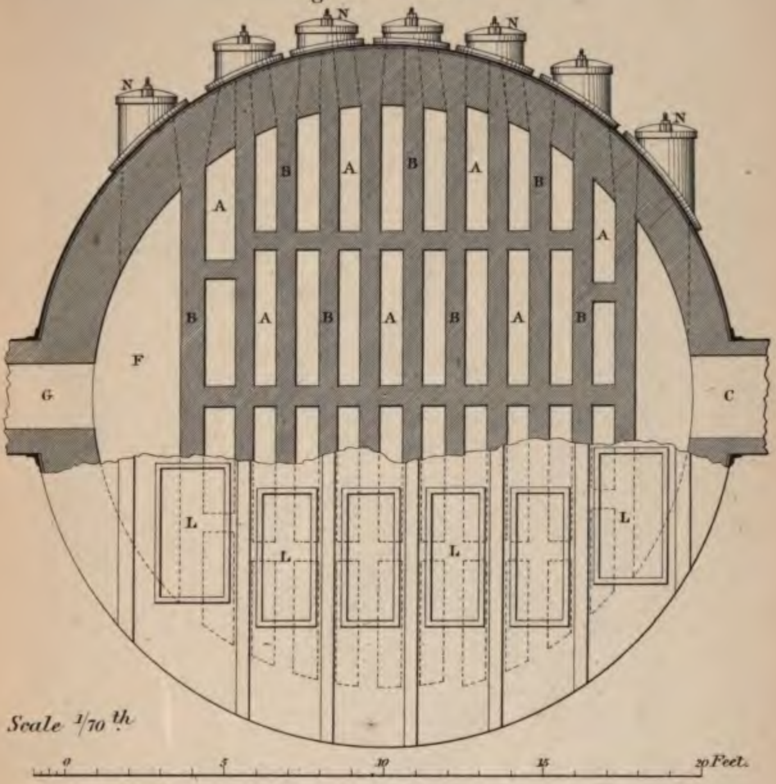
REGENERATIVE HOT-BLAST STOVES. *Plate 16.*

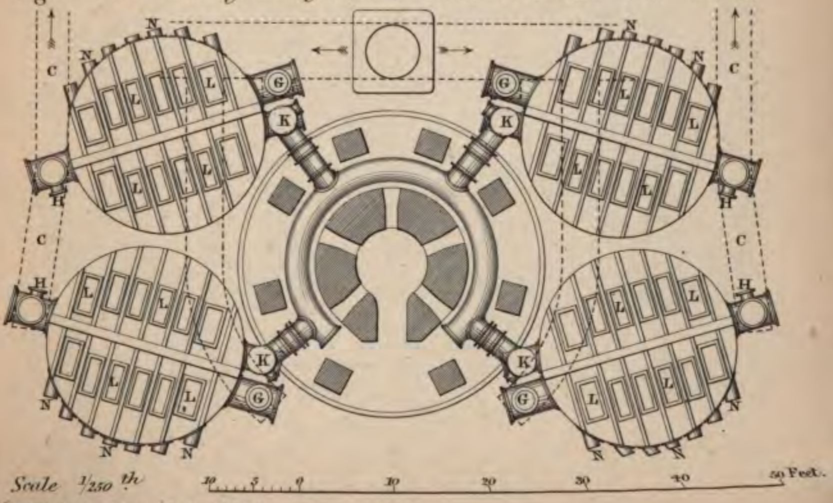
Regenerative Stove with Firebrick Walls at Consett Iron Works.

Fig. 19. *Plan.*



Scale 1/70th.

Fig. 20. *Plan showing arrangement of Stoves at Consett Iron Works.*



Scale 1/250th

(Proceedings Inst. M. E. 1870.)

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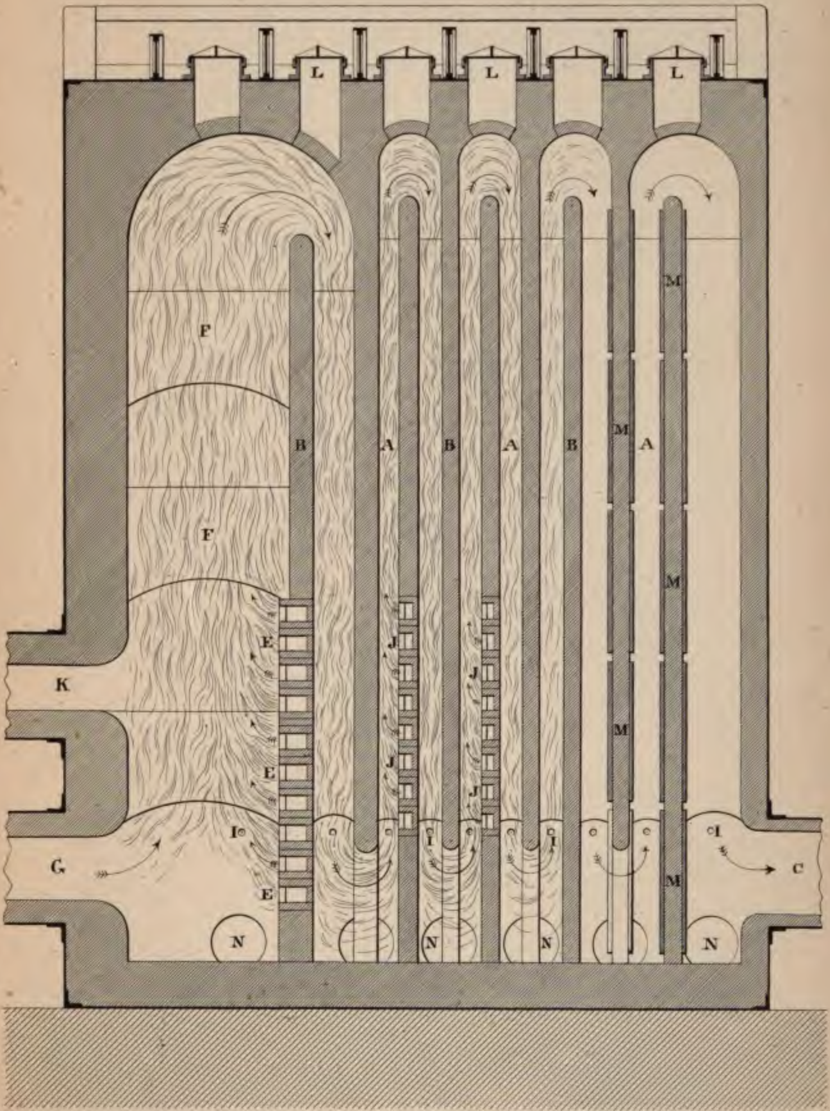
REGENERATIVE HOT-BLAST STOVES. *Plate 17.*

Improved Regenerative Stove with Firebrick Walls

at Consett Iron Works.

Fig. 21. *Vertical Section.*



Scale 1/70th

(Proceedings Inst. M.E. 1870)

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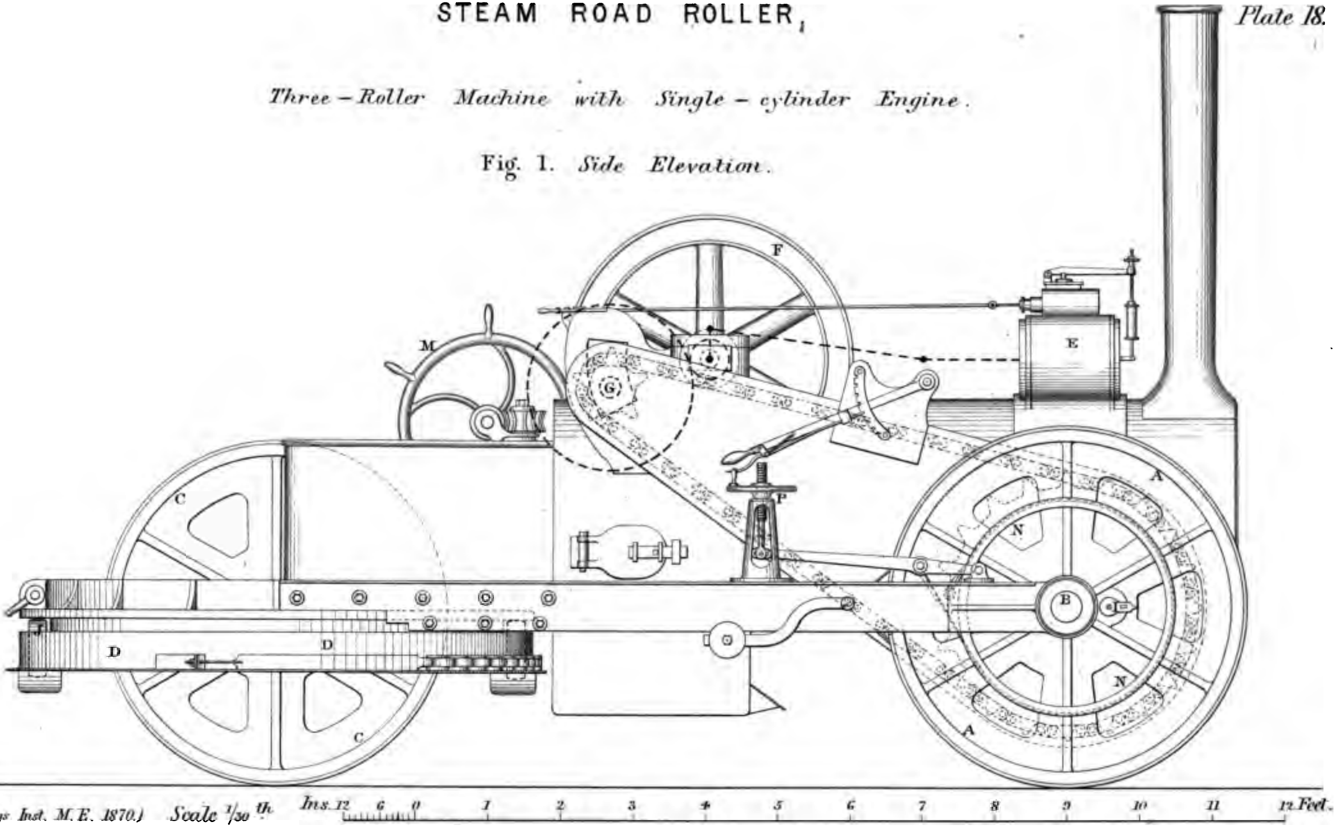
Plate 18.

STEAM ROAD ROLLER,

Three-Roller Machine with Single-cylinder Engine.

Fig. 1. *Side Elevation.*



(Proceedings Inst. M.E. 1870.) Scale 1/30th.

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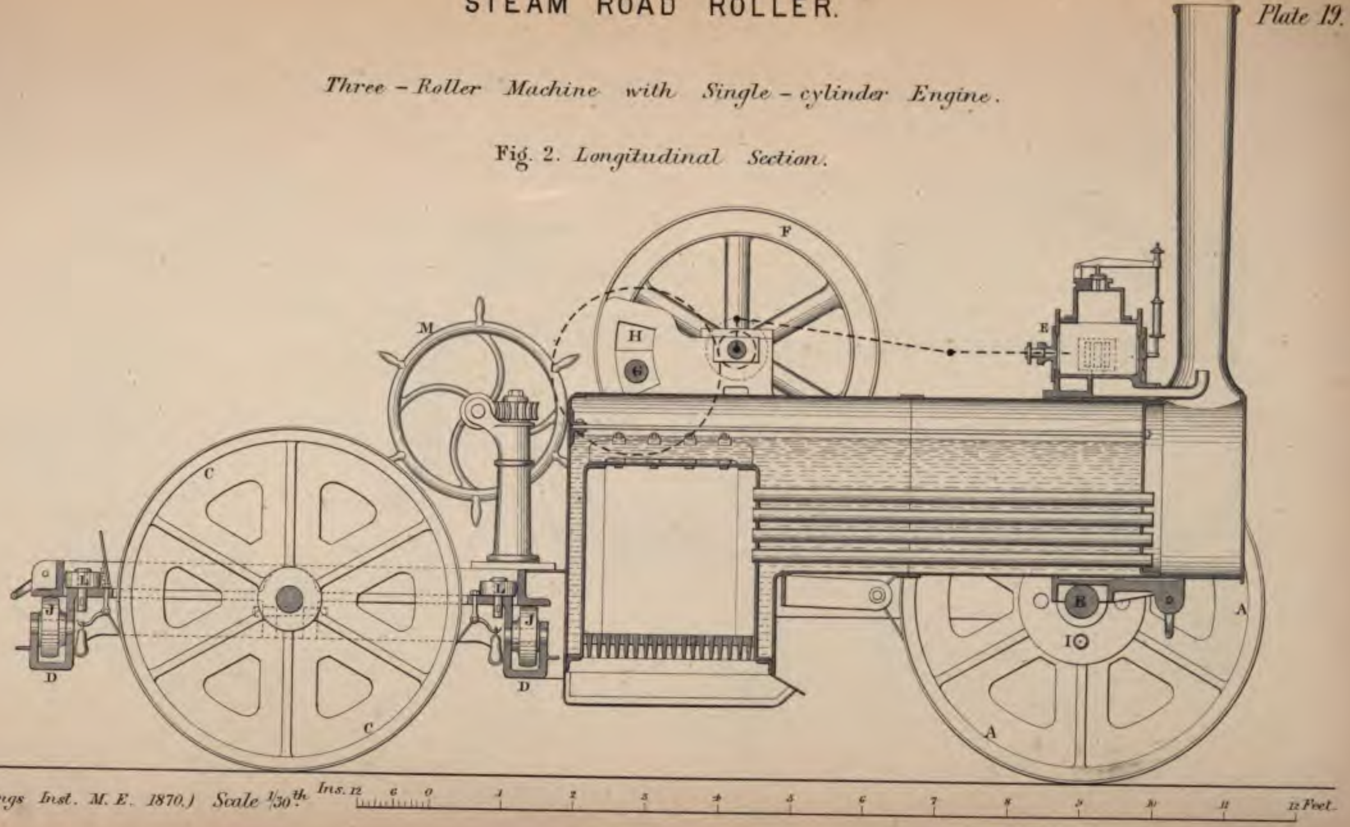
N.Y.

Plate 19.

STEAM ROAD ROLLER.

Three-Roller Machine with Single-cylinder Engine.

Fig. 2. *Longitudinal Section.*



(Proceedings Inst. M. E. 1870.) *Scale $1/30^{th}$.*

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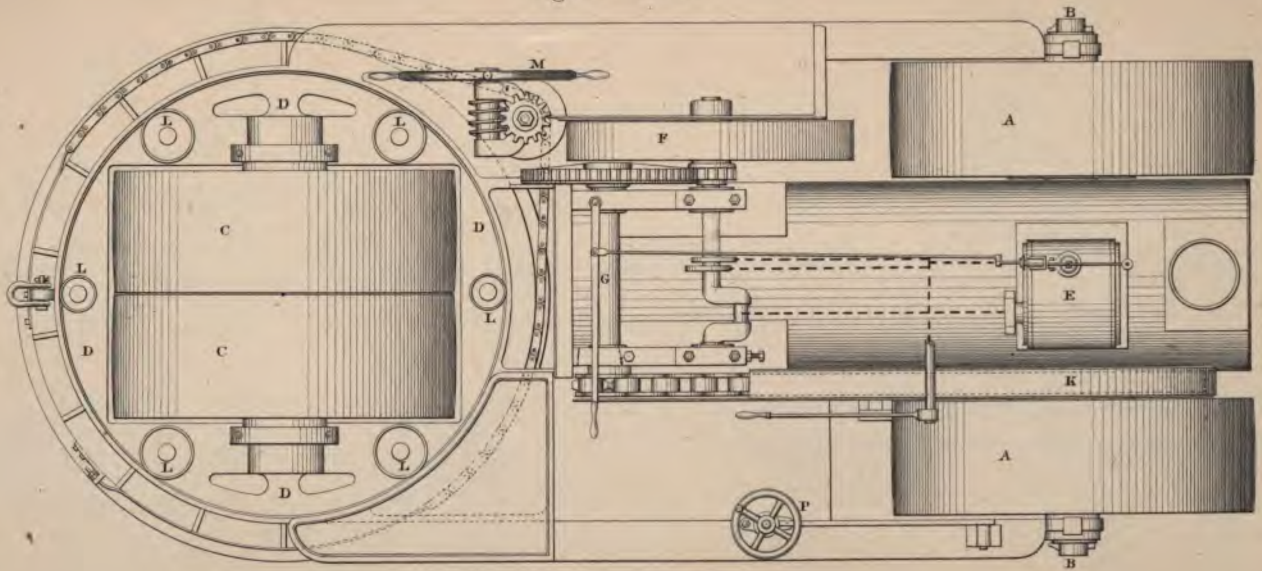
NY

Plate 20.

STEAM ROAD ROLLER.

Three - Roller Machine with Single - cylinder Engine.

Fig. 3. *Plan.*



(Proceedings Inst. M. E. 1870) *Scale 1/30th* *Ins.* 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 *Feet.*

THE ASTOR LIBRARY

STEAM ROAD ROLLER.

Three - Roller Machine
with Single - cylinder Engine.

Fig. 4. *Back Elevation.*

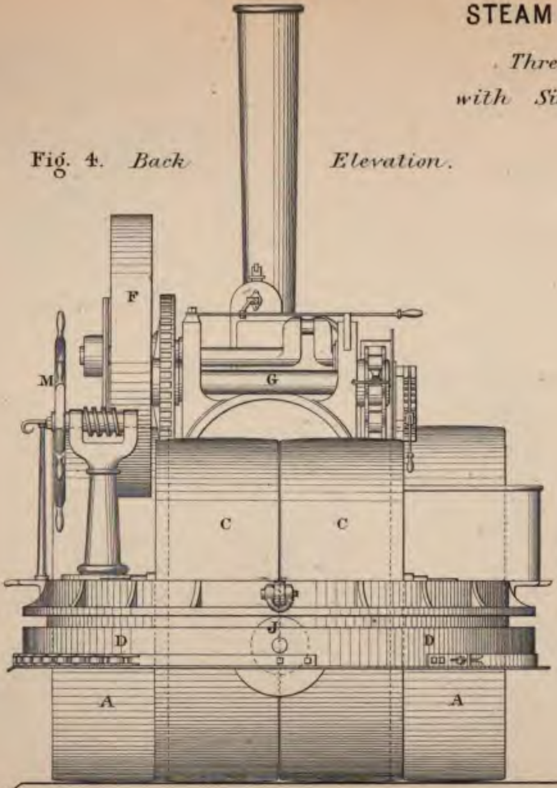
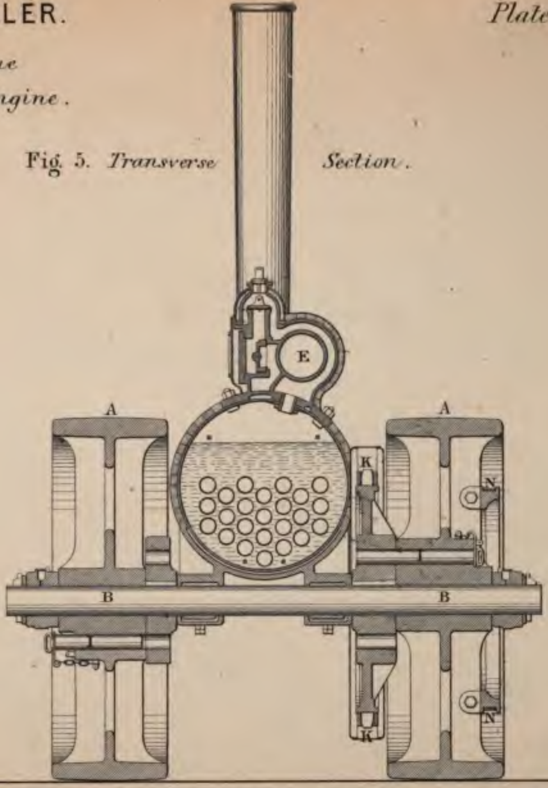


Fig. 5. *Transverse Section.*



(Proceedings Inst. M.E. 1870.) Scale $1/30^{th}$. Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

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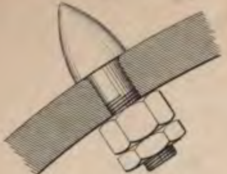
STEAM ROAD ROLLER.

Fig. 7. *Spikes for breaking up road surface.*

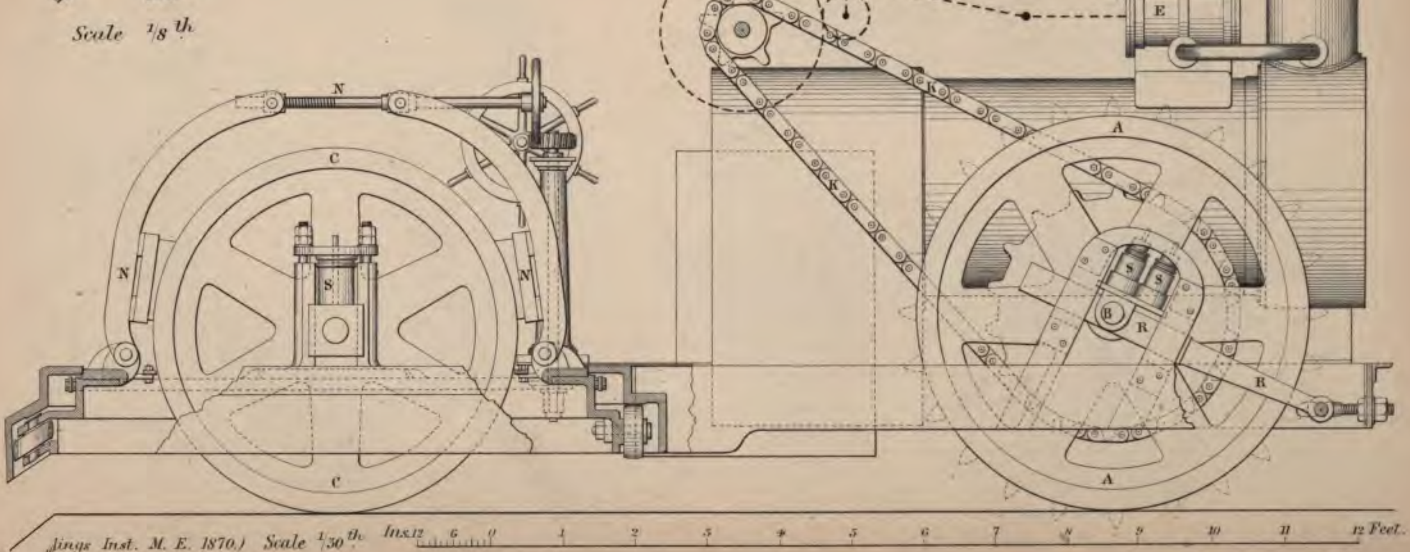


Scale 1/8th.

Three - Roller Machine

with Double - cylinder Engine and Bearing Springs.

Fig. 6. *Side Elevation.*



(Proceedings Inst. M. E. 1870.) *Scale* 1/30th.

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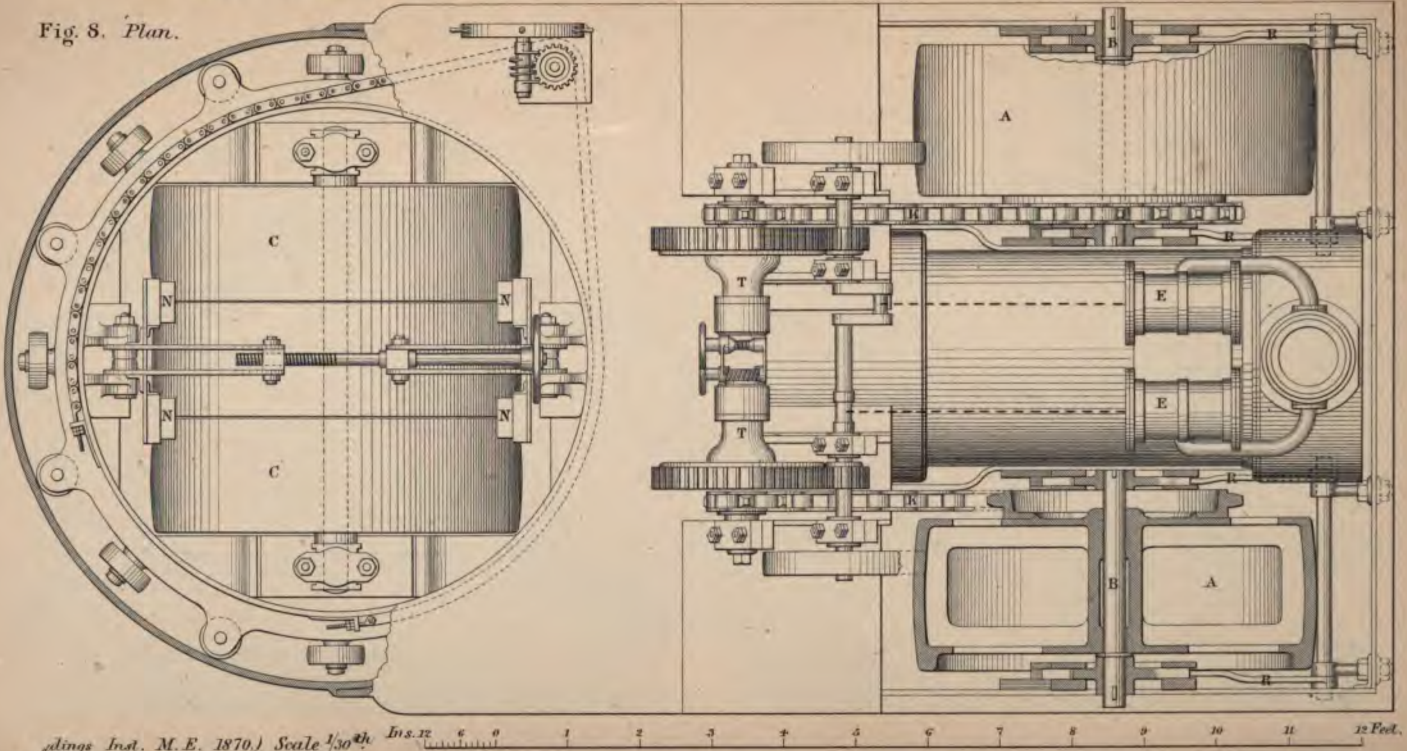
Plate 23.

STEAM ROAD ROLLER.

Three-Roller Machine with Double-cylinder Engine and Bearing Springs.

Fig. 8. *Plan.*



(Proceedings Inst. M.E. 1870.) Scale 1/30th

Plate 24.

STEAM ROAD ROLLER.

Three - Roller Machine

with Double - cylinder Engine and Bearing Springs.

Fig. 9.

Back Elevation.

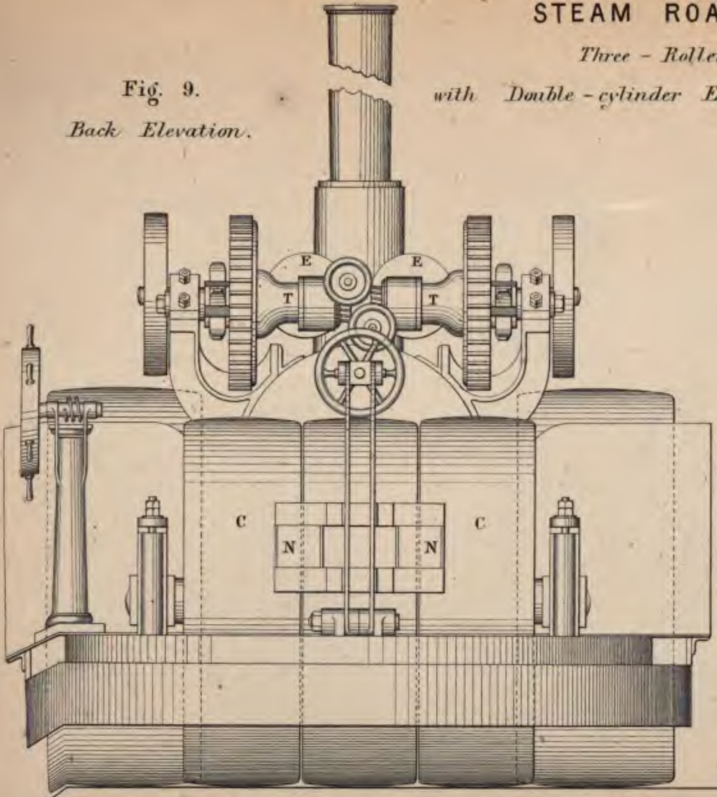
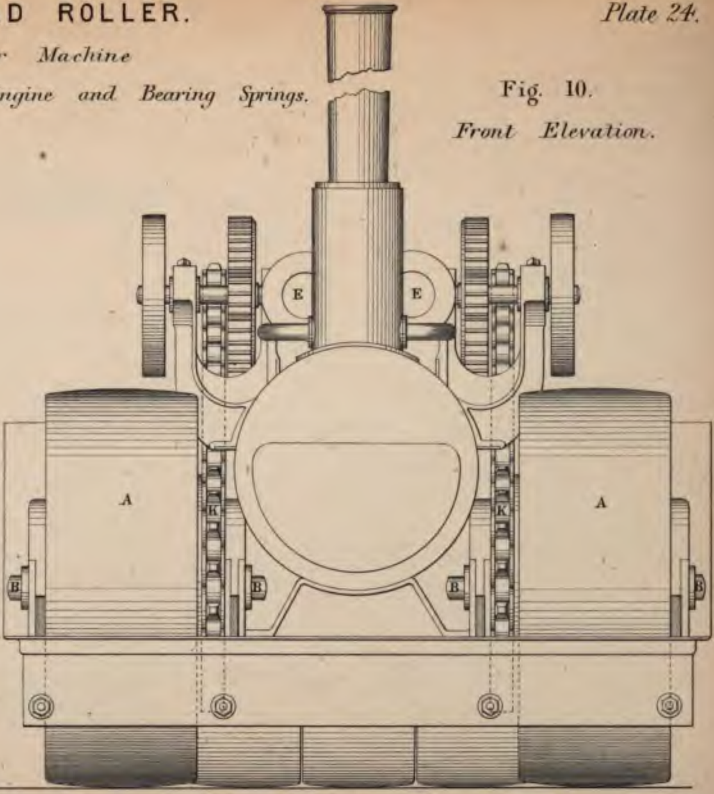


Fig. 10.

Front Elevation.



Scale 1/30 th. Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

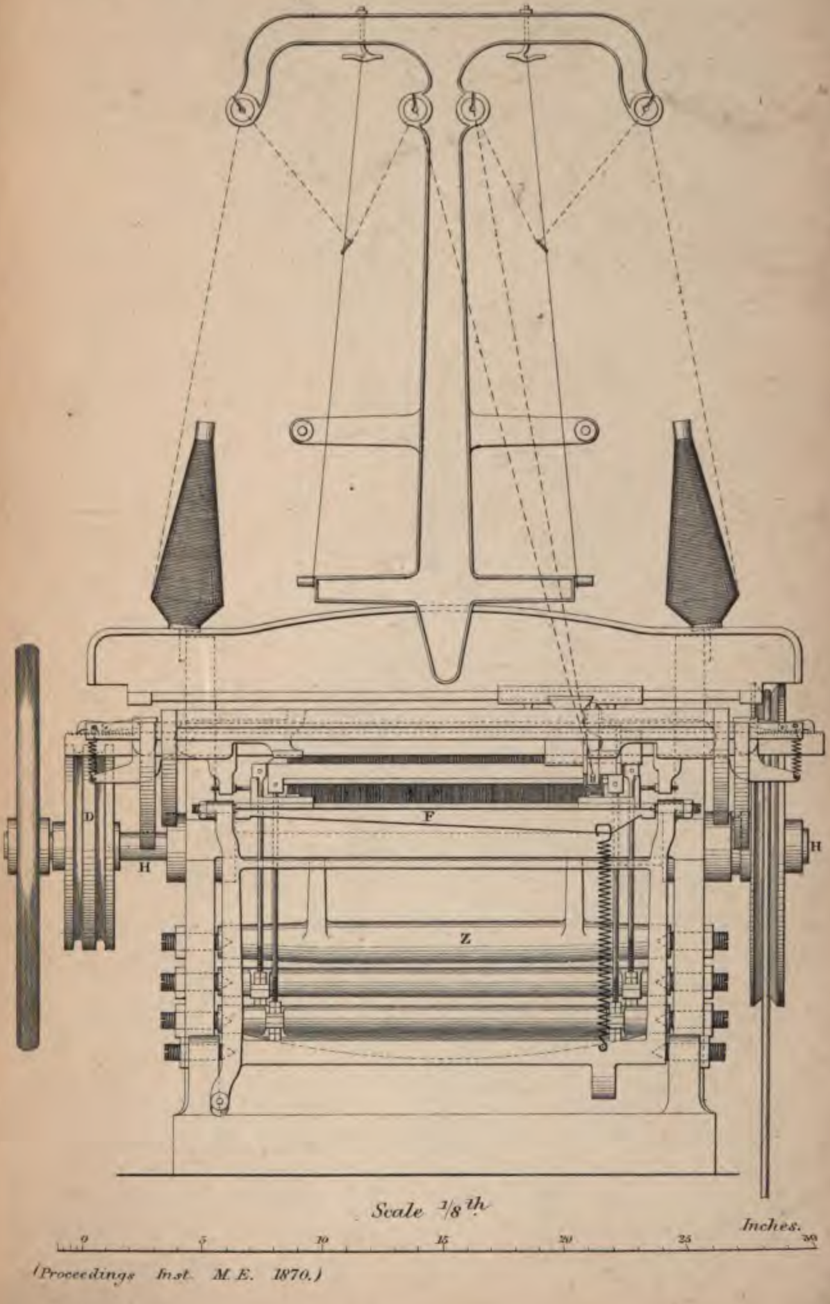
(Proceedings Inst. M.E. 1870.)

[illegible] LIBRARY

KNITTING MACHINE.

Plate 25.

Fig. 1. *Front View of Self-acting Knitting Machine.*



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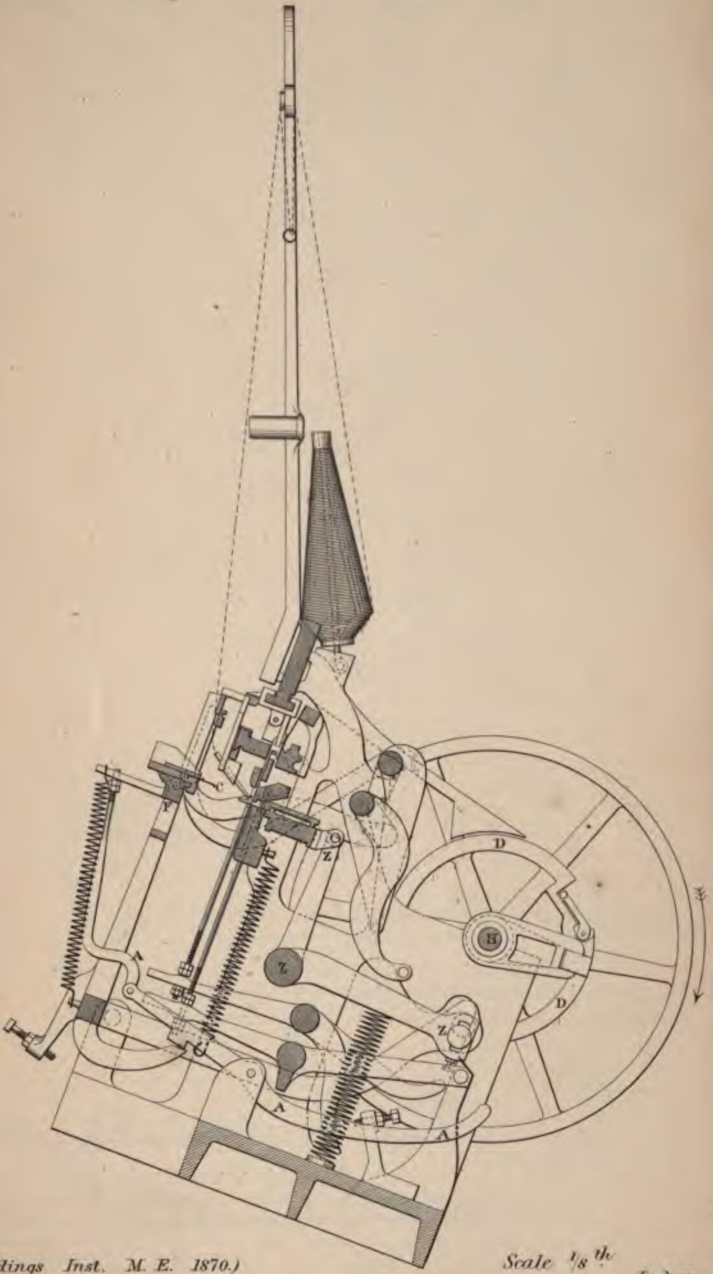
KNITTING MACHINE.

Plate 26.

Fig. 2. *Transverse Section of Self-acting Knitting Machine.*



(Proceedings Inst. M. E. 1870.)

Scale $^1/_8{}^{th}$

Inches.

0 5 10 15 20 25 30

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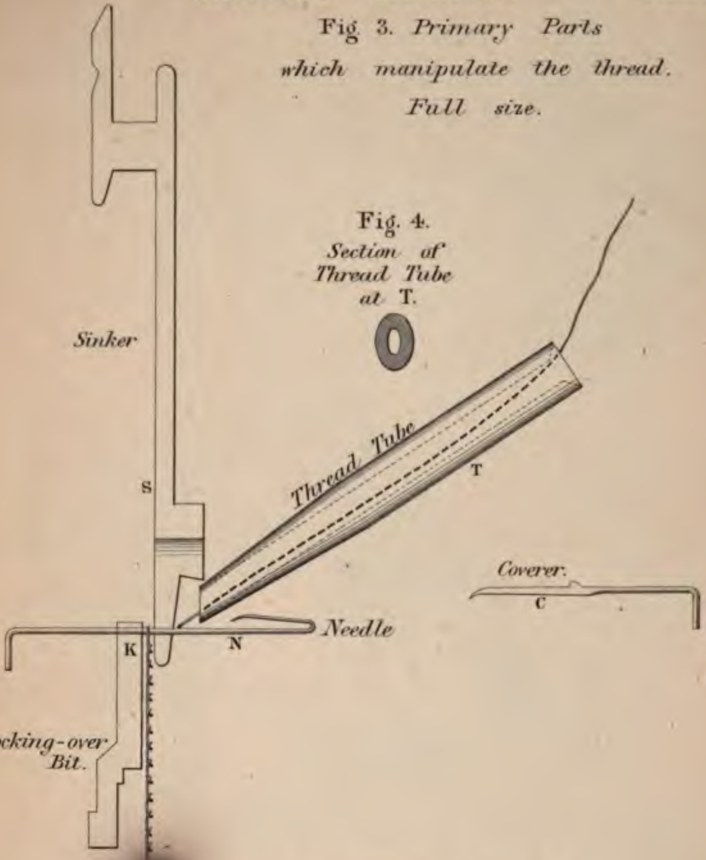
KNITTING MACHINE.

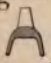
Fig. 3. *Primary Parts which manipulate the thread. Full size.*

Fig. 4. *Section of Thread Tube at* T.



Enlarged Details, 4 times full size.

Fig. 5.



Section at C.

Fig. 6. *Coverer.*

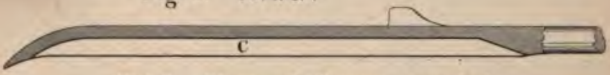


Fig. 7. *Plan of Coverer, inverted.*

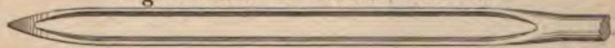


Fig. 8. *Needle.*

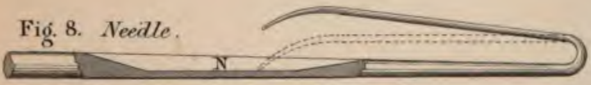
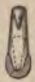


Fig. 9.



Section at N.

Fig. 10. *Plan of Needle.*

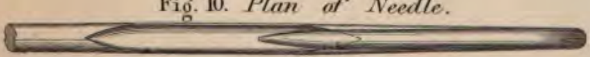


Fig. 11. *Knocking-over Bit, Section at* K.

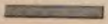
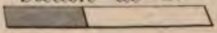


Fig. 12. *Sinker, Section at* S.



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KNITTING MACHINE.

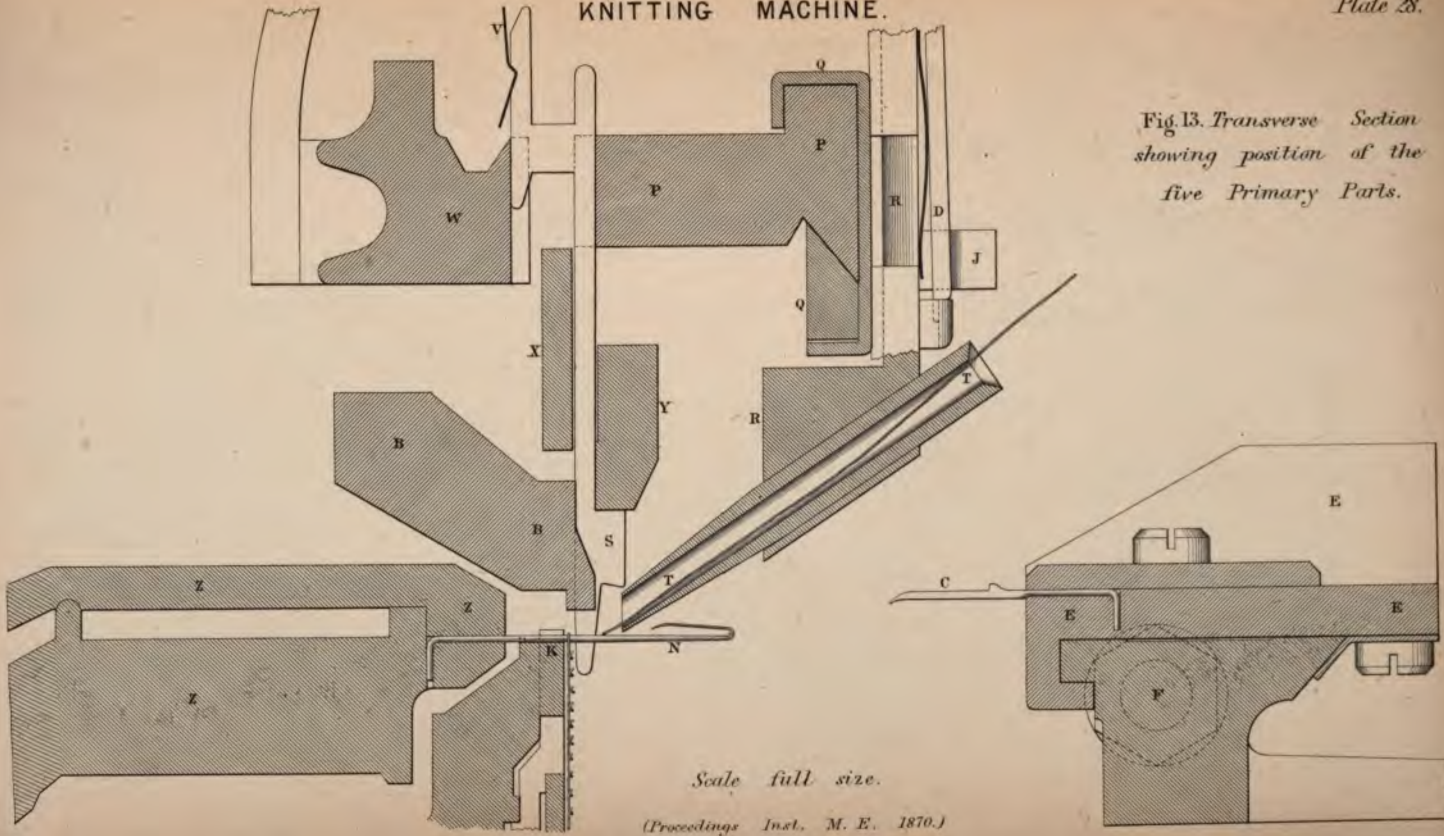


Fig. 13. *Transverse Section showing position of the five Primary Parts.*

Scale full size.

(Proceedings Inst. M. E. 1870.)

KNITTING MACHINE.

Fig. 14. *Front Elevation of Sinkers and Sinker Incline.*

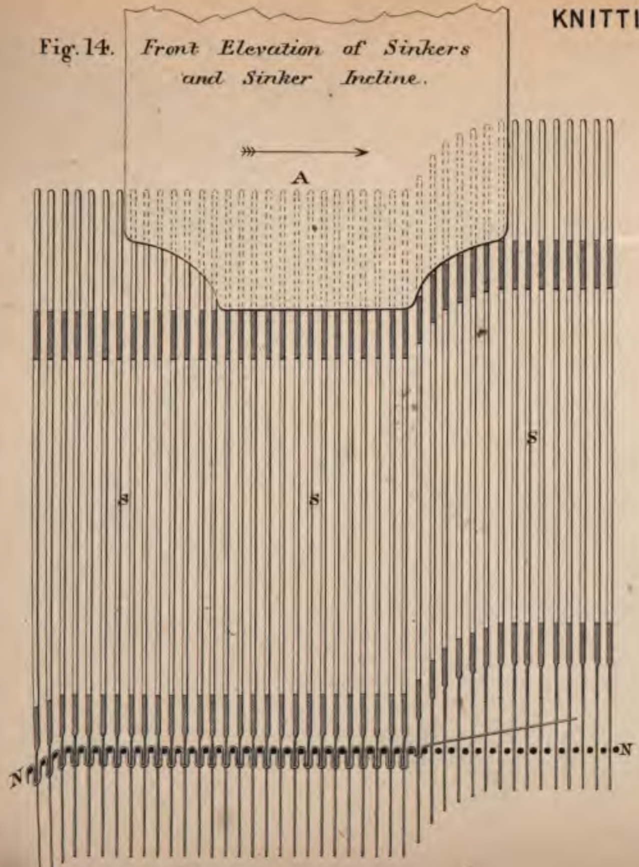


Fig. 15. *Knitted Web, showing Narrowing.*

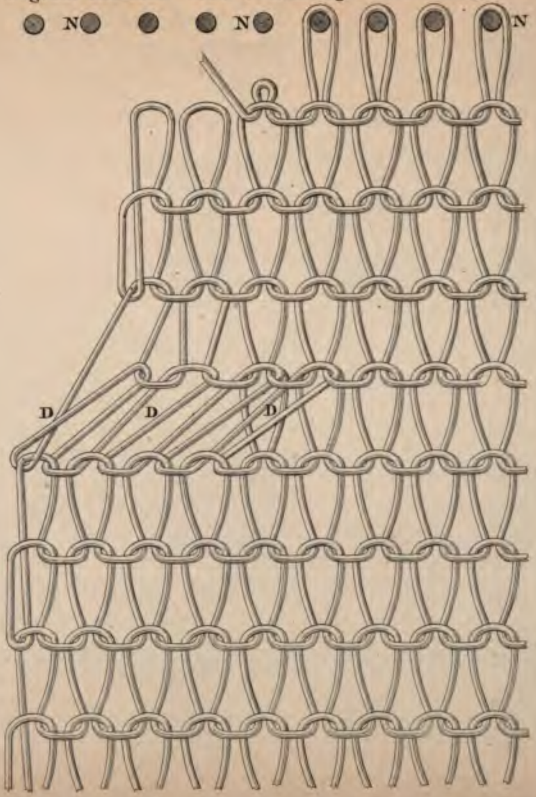
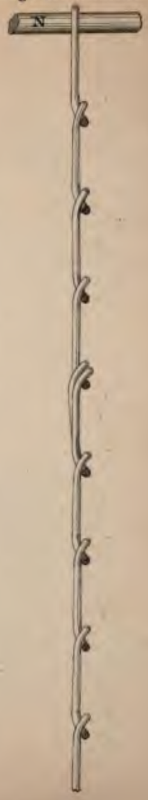


Fig. 16. *Section.*



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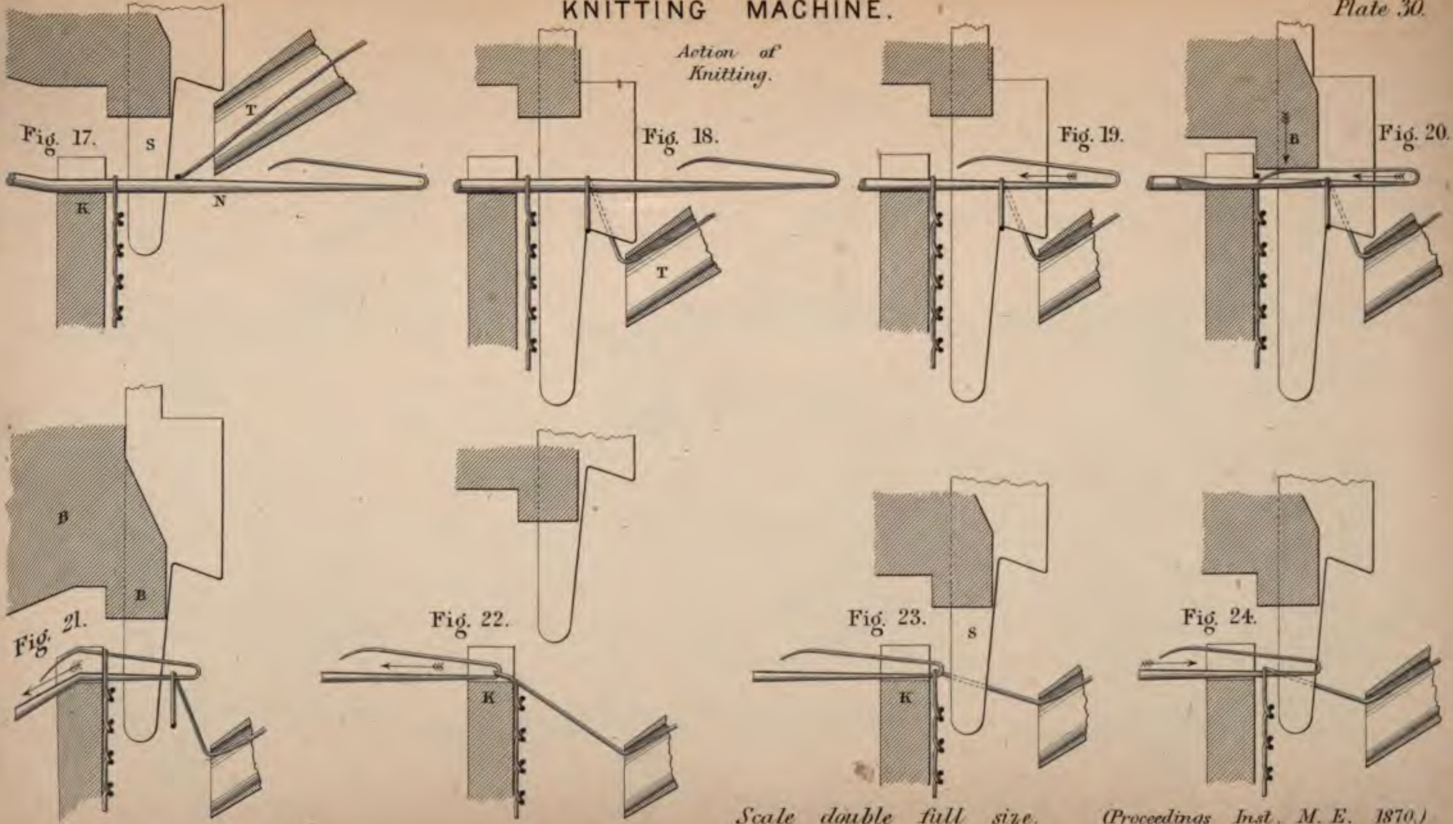
KNITTING MACHINE.

Action of Knitting.



Scale double full size.

(Proceedings Inst. M. E. 1870.)

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KNITTING MACHINE.

Plate 31.

Action of Narrowing.

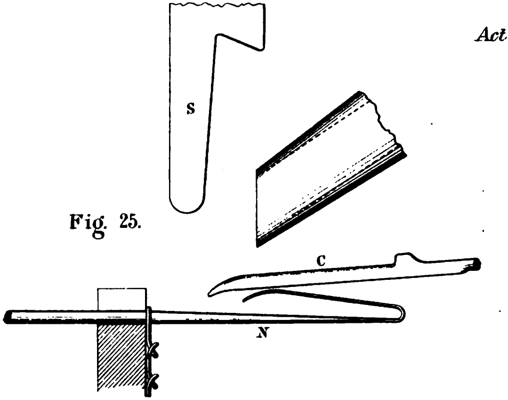

Fig. 25.

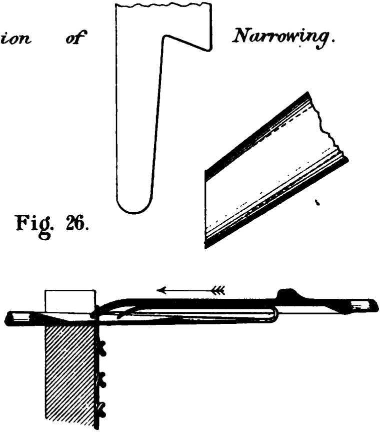

Fig. 26.

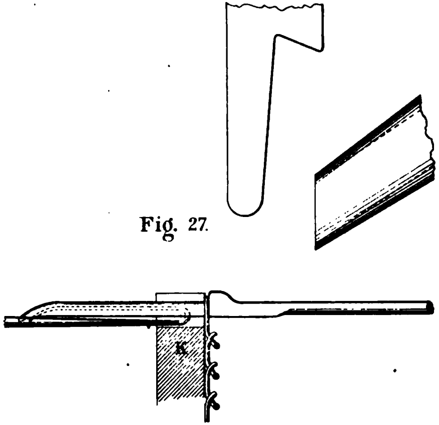

Fig. 27.

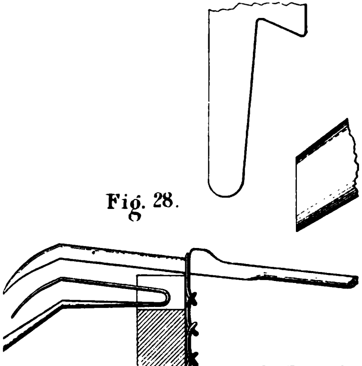

Fig. 28.

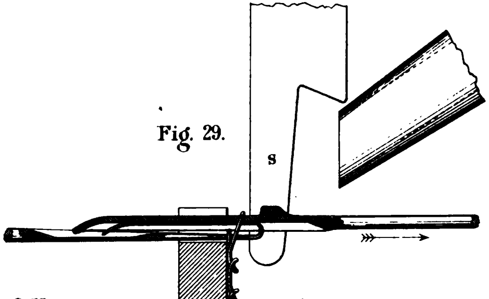

Fig. 29.

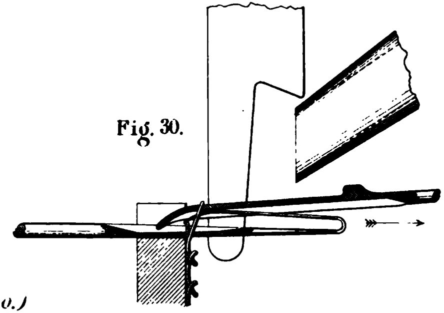

Fig. 30.

Scale double full size.

(Proceedings Inst. M. E. 1870.)

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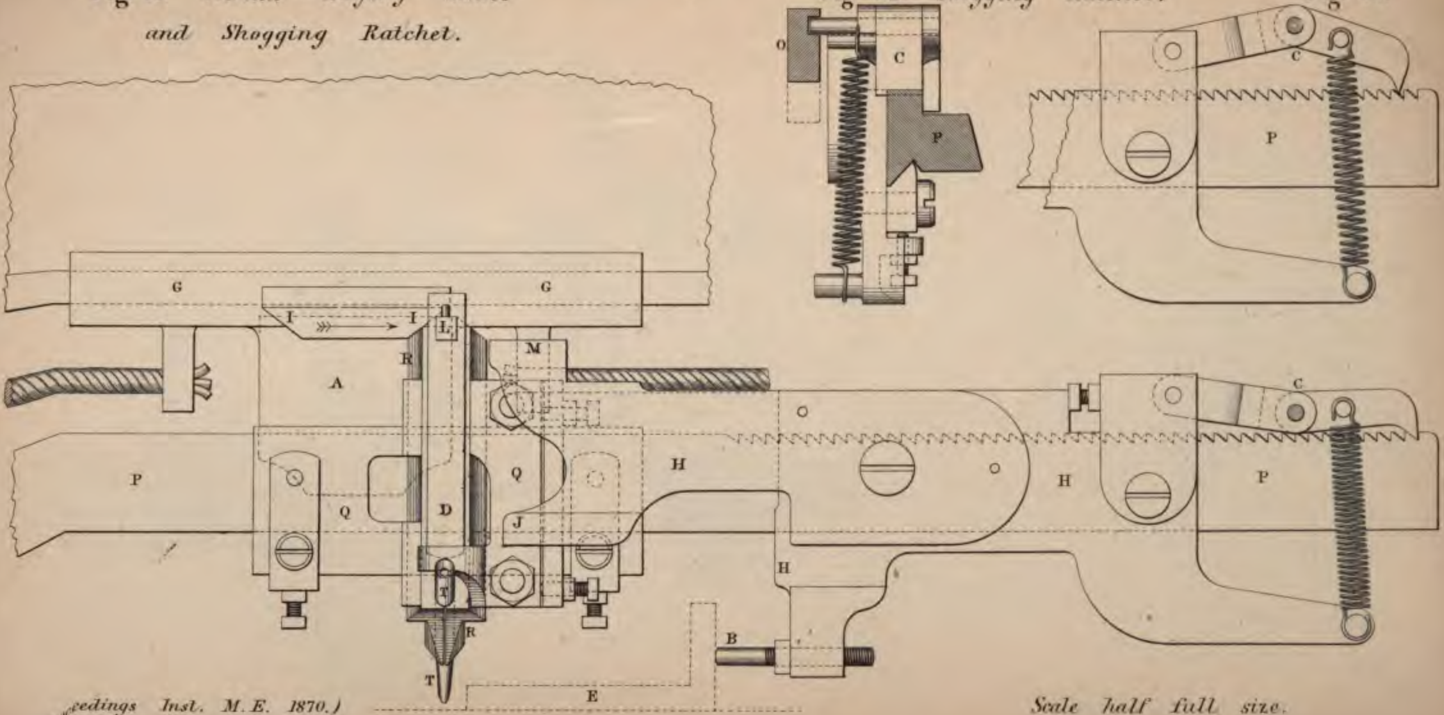
KNITTING MACHINE.

Plate 32.

Fig. 31. *Thread - Laying Slides and Shogging Ratchet.*

Fig. 32. *Shogging Ratchet.* Fig. 33.



(Proceedings Inst. M. E. 1870.)

Scale half full size.

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KNITTING MACHINE.

Fig. 34. *Thread-Laying Slides and Sinker Incline.*

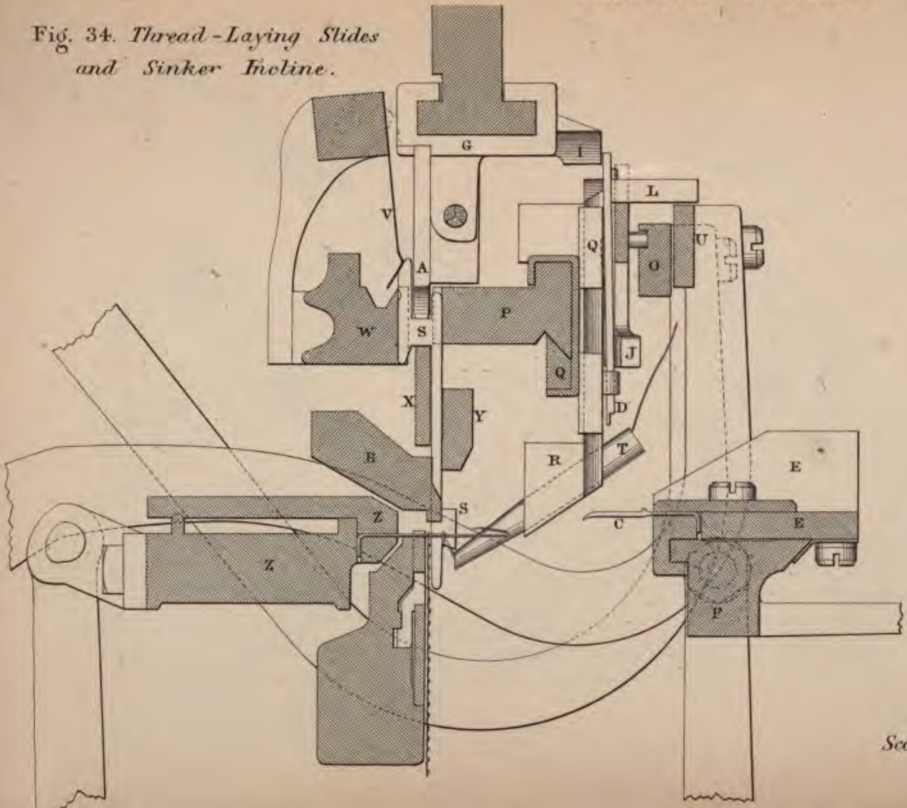
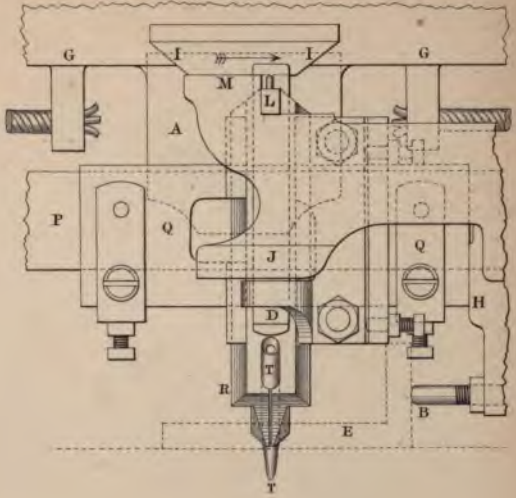


Fig. 35. *Thread-Laying Slides. Thread-Tube lowered at end of course.*



Scale half full size.

(Proceedings Inst. M.E. 1870.)

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KNITTING MACHINE.

Drawing-Across Pulley, for traversing the Thread-Laying Slides.

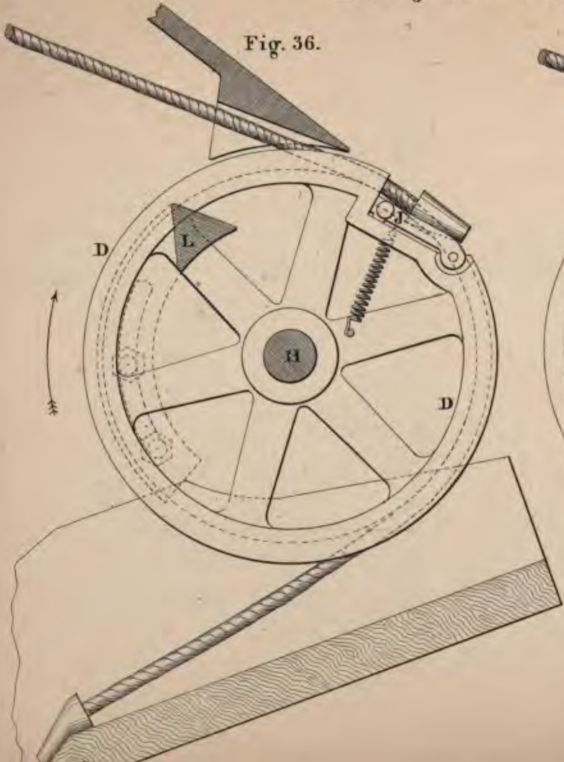

Fig. 36.

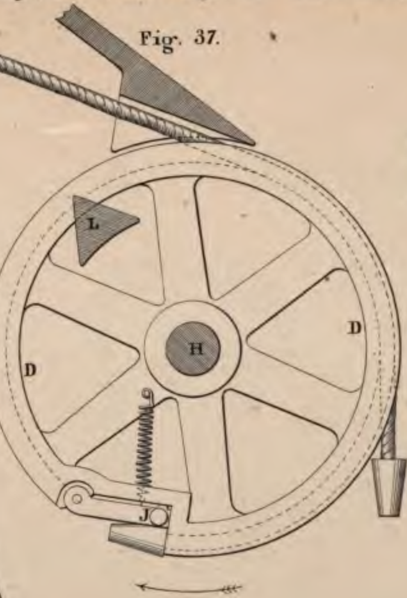

Fig. 37.

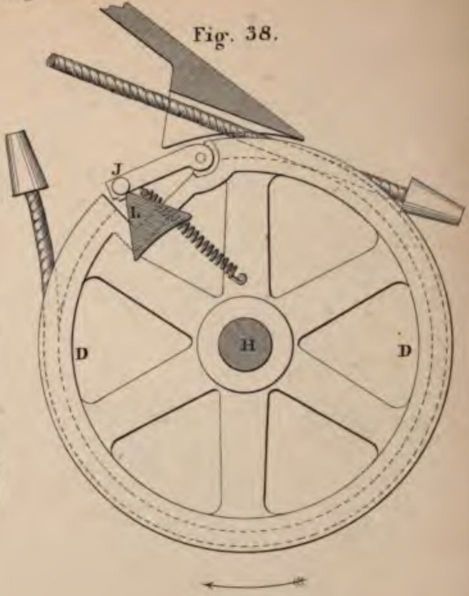

Fig. 38.

Scale 1/4th.

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KNITTING MACHINE.

Drawing-Across Pulley,
out of gear during Narrowing.

Fig. 39.
Back Elevation.

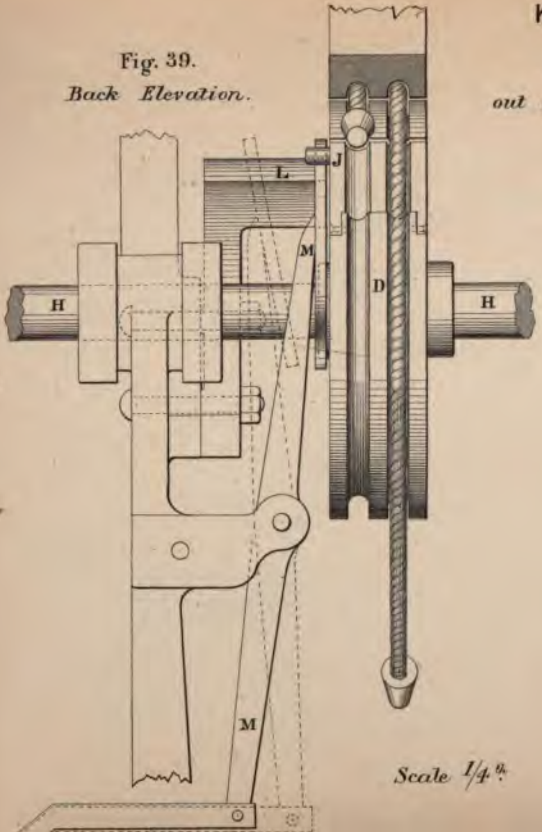
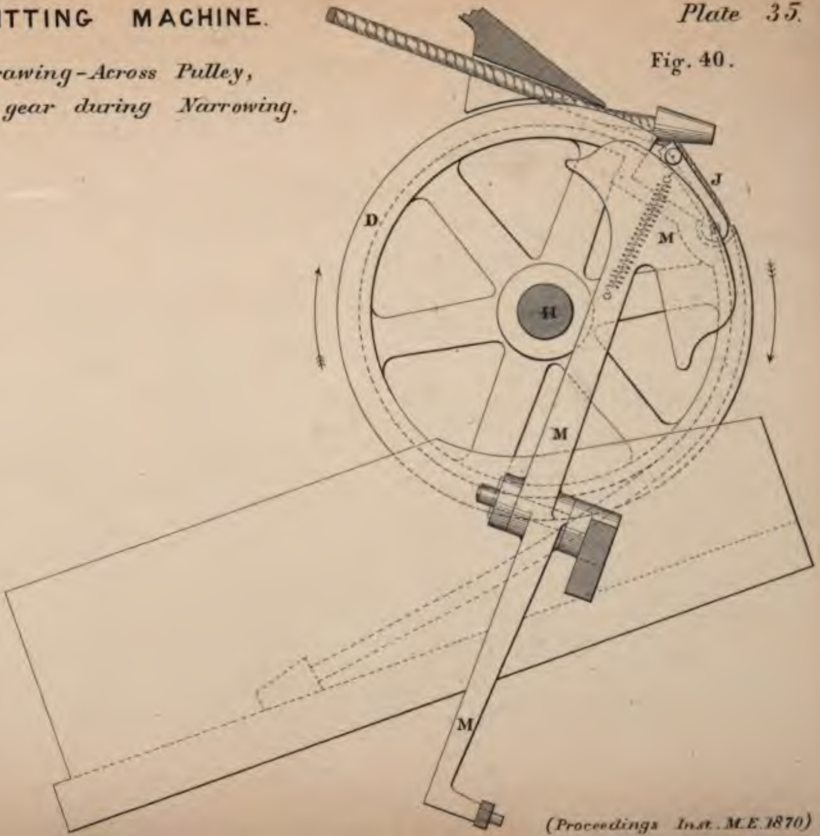


Fig. 40.



Scale 1/4th.

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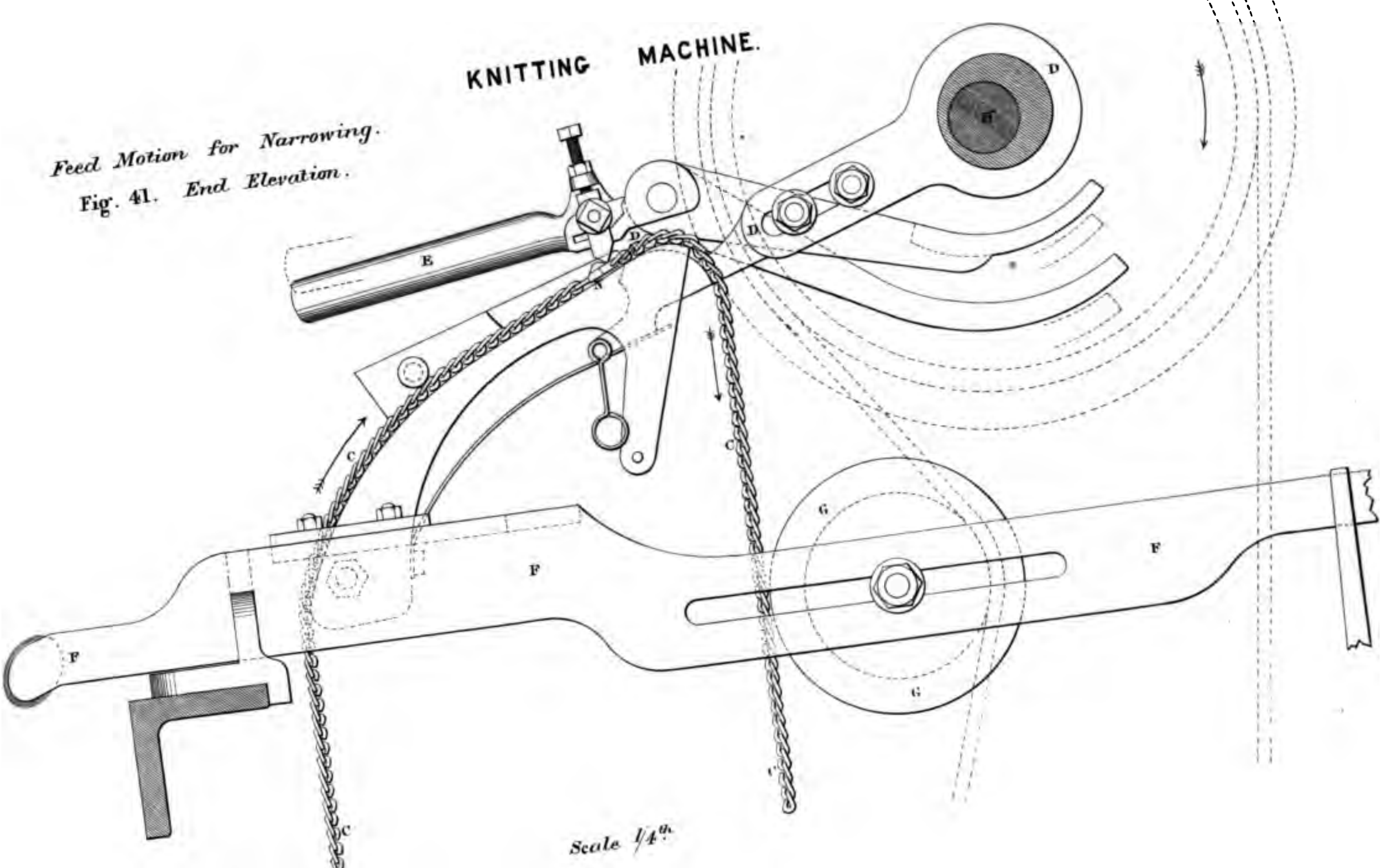
KNITTING MACHINE.

Feed Motion for Narrowing.

Fig. 41. End Elevation.



Scale 1/4th.

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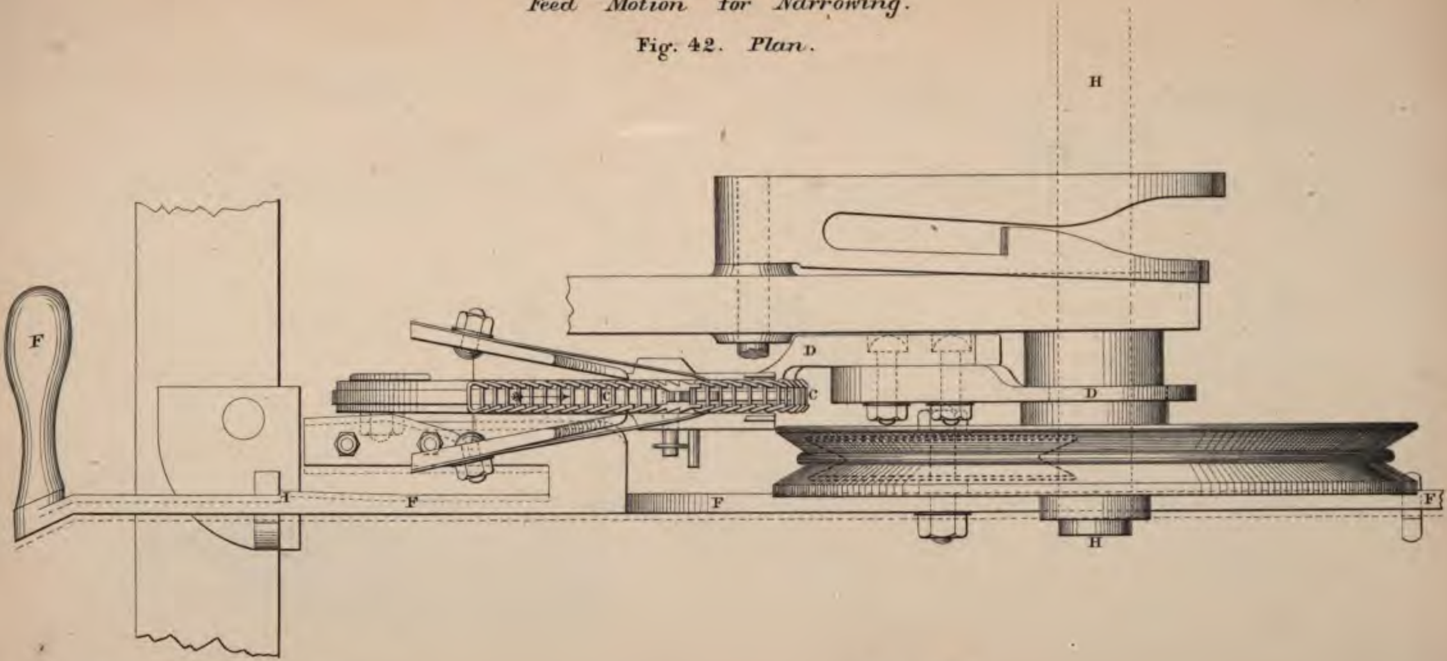
Plate 37.

KNITTING MACHINE.

Feed Motion for Narrowing.

Fig. 42. *Plan.*



Scale 1/4th

(Proceedings Inst. M.E. 1870.)

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KNITTING MACHINE.

Feed Motion for Narrowing.

Fig. 43. *Side View of Chain.*

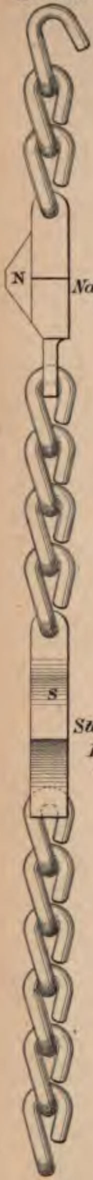
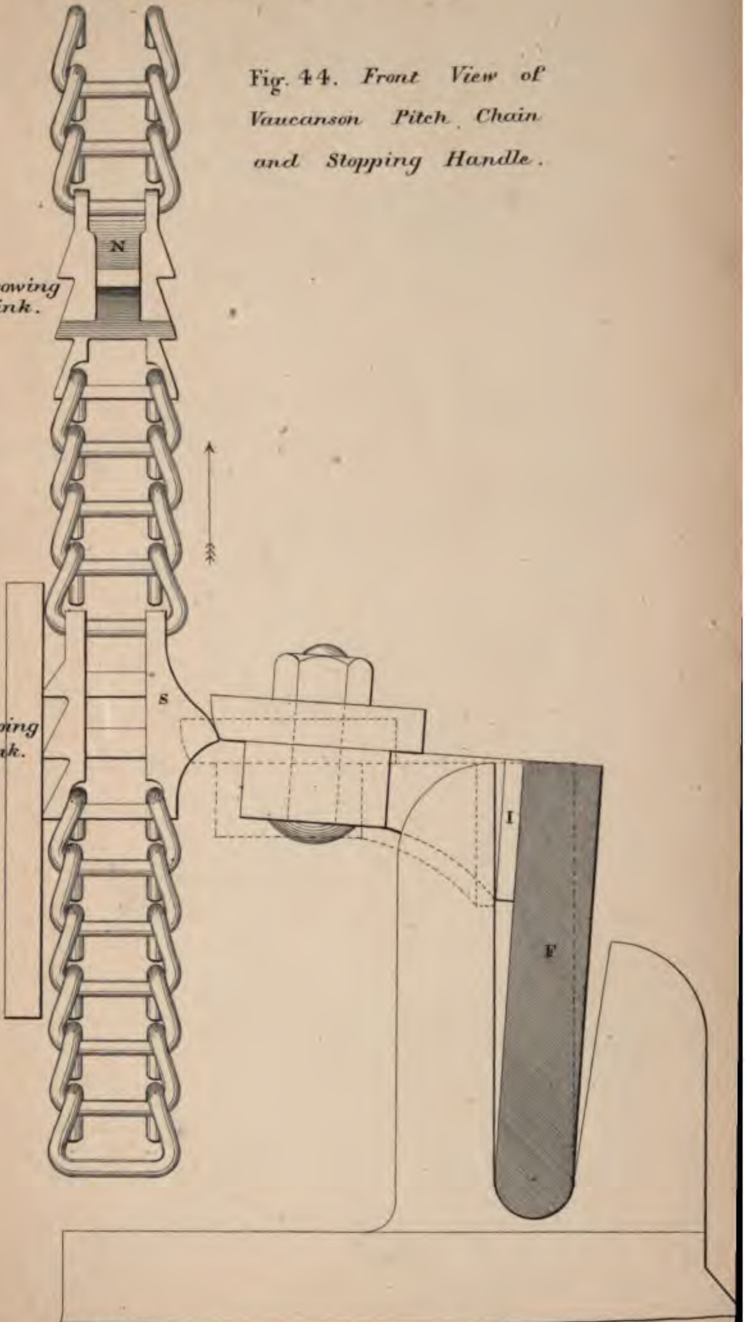


Fig. 44. *Front View of Vaucanson Pitch Chain and Stopping Handle.*



Full size.

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KNITTING MACHINE.

Plate 39.

Cam Traverse Motion.

Fig. 45. *Position for Knitting.*

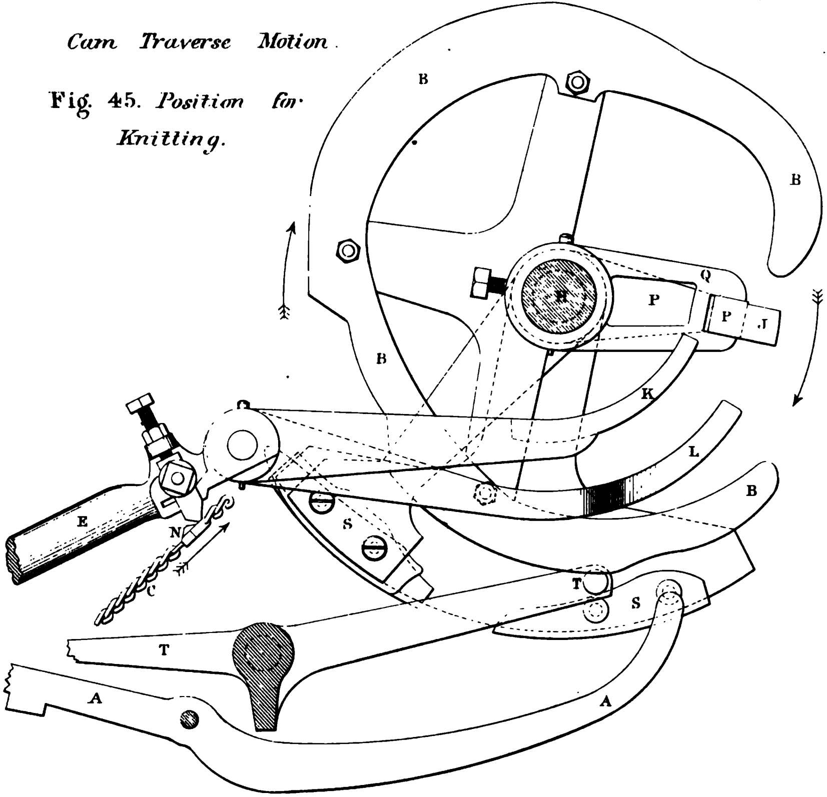
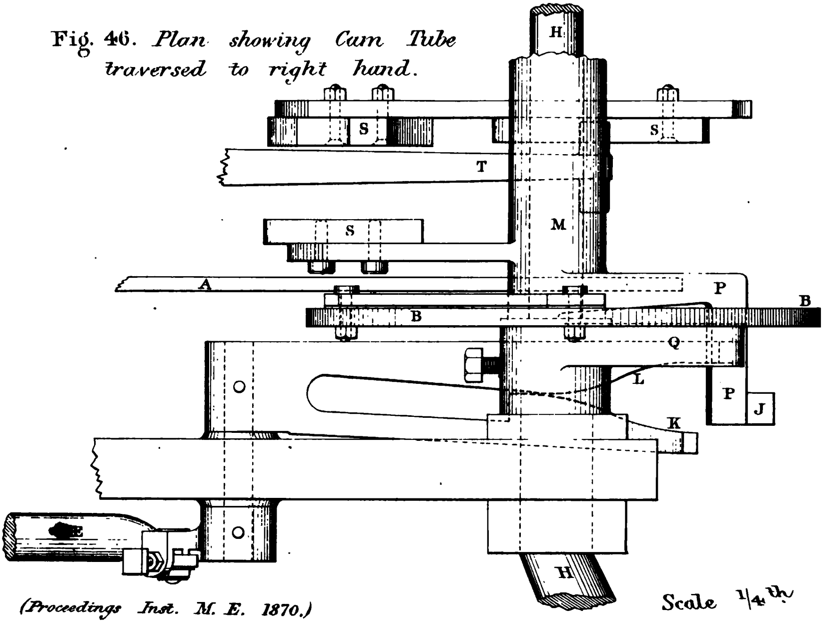


Fig. 46. *Plan showing Cam Tube traversed to right hand.*



(Proceedings Inst. M. E. 1870.)

Scale 1/4th

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KNITTING MACHINE. *Plate 40.*

Cam Traverse Motion.

Fig. 47. *Position for Narrowing.*

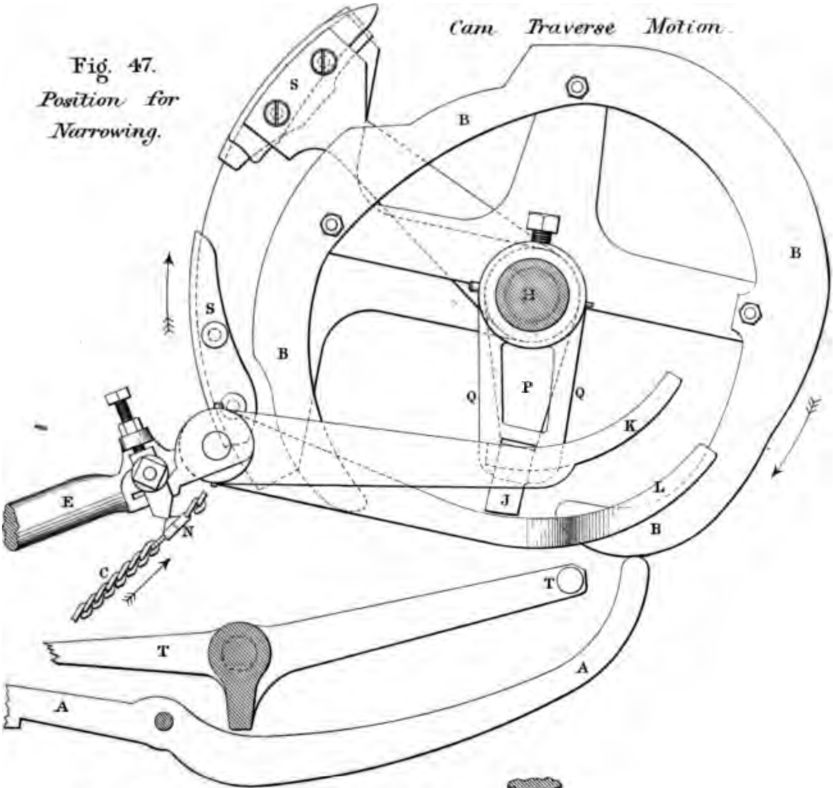
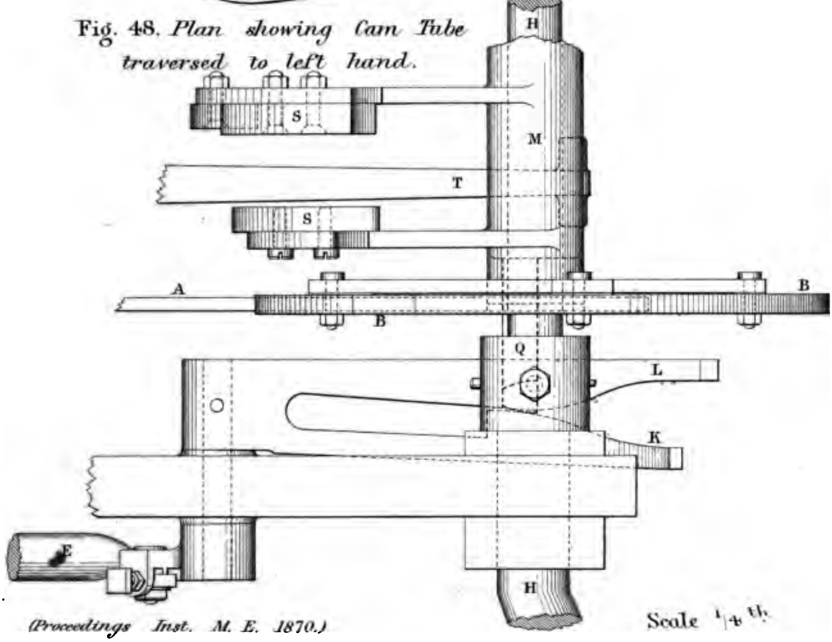


Fig. 48. *Plan showing Cam Tube traversed to left hand.*



(Proceedings Inst. M. E. 1870.)

Scale ¼th.

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KNITTING MACHINE.

Plate 41.

Cam Traverse Motion.

Diagrams showing Traversing of Cam Tube,

(looking at back of machine).

Fig. 49. *Cam Tube traversed to right hand for Knitting.*

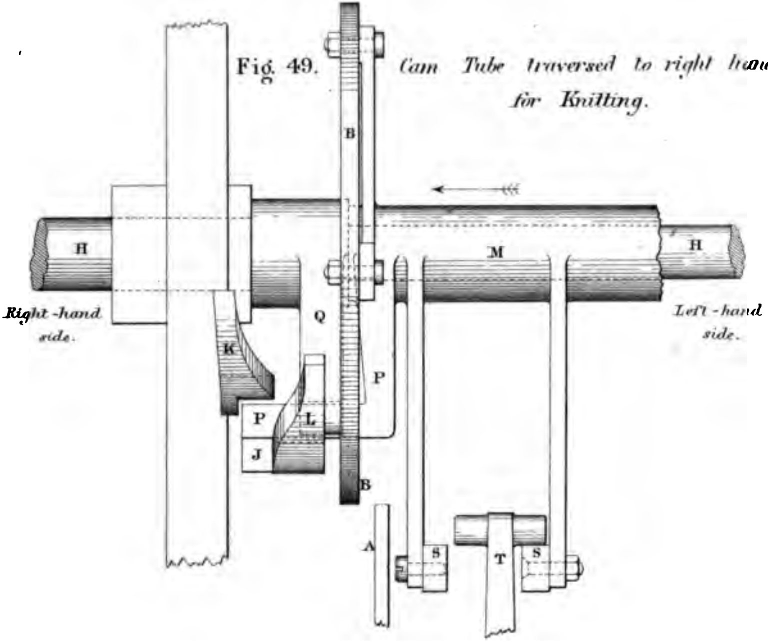
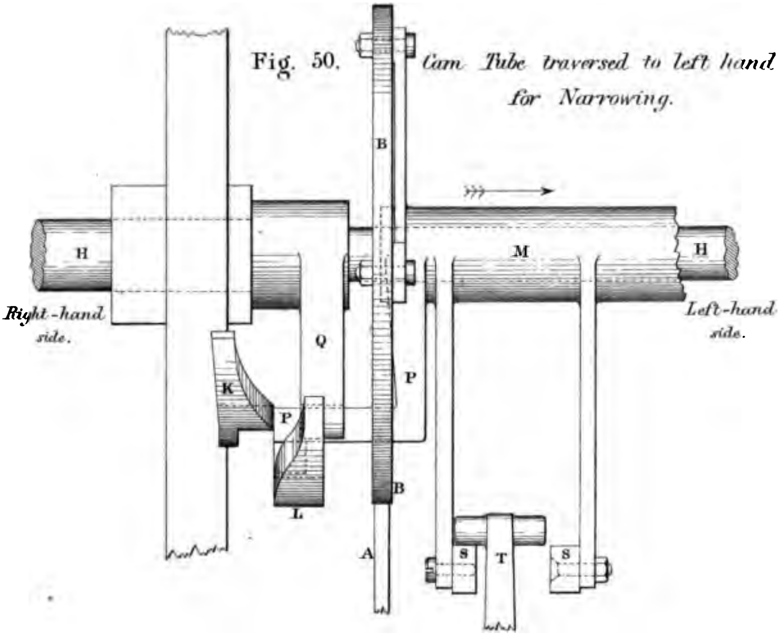


Fig. 50. *Cam Tube traversed to left hand for Narrowing.*



(Proceedings Inst. M. E. 1870.)

Scale $1/4^{th}$

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MIDLAND COLLIERY WORKING.

Fig. 1. *Section of Pillar Working.*

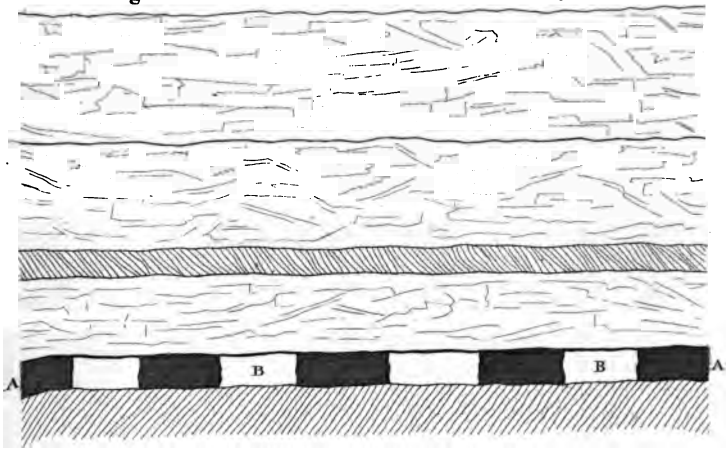


Fig. 2. *Section of Longwall Working.*

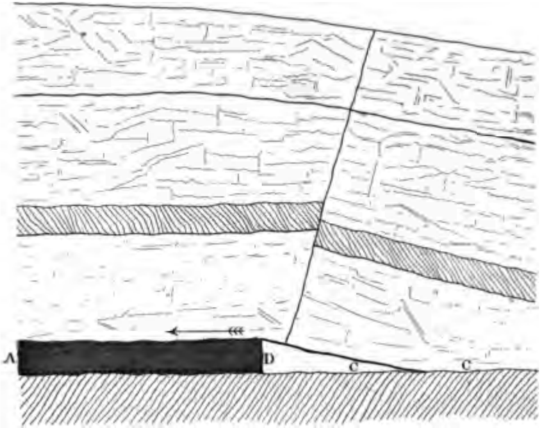


Fig. 3. *Haulage by Main and Tail Ropes or Endless Rope, carried upon rollers and drawing a train of wagons.*

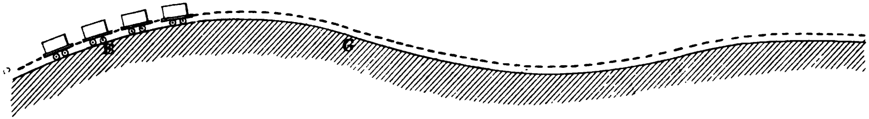
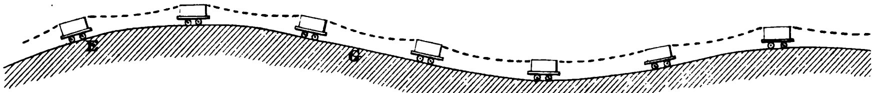


Fig. 4. *Haulage by Endless Chain carried upon wagons spaced at intervals, without rope rollers.*



(Proceedings Inst. M.E. 1870.) *Scale 1/350th.*

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End Turning Pulley, for haulage by endless chain.

Fig. 5. *End Elevation.*

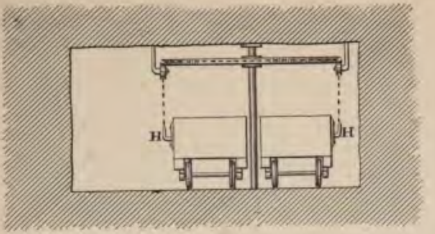


Fig. 6. *Side Elevation.*

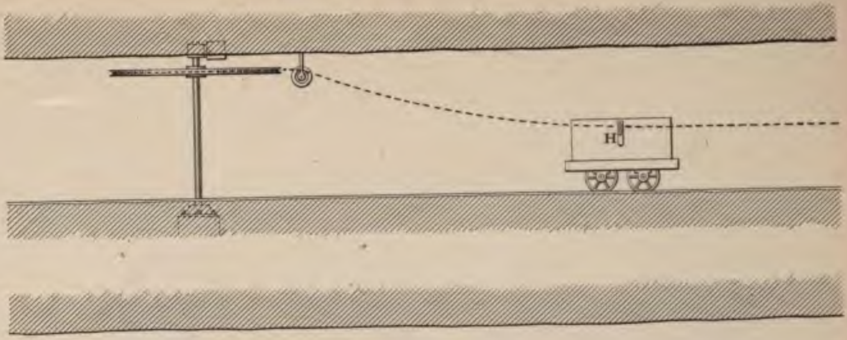


Fig. 7. *Plan.*

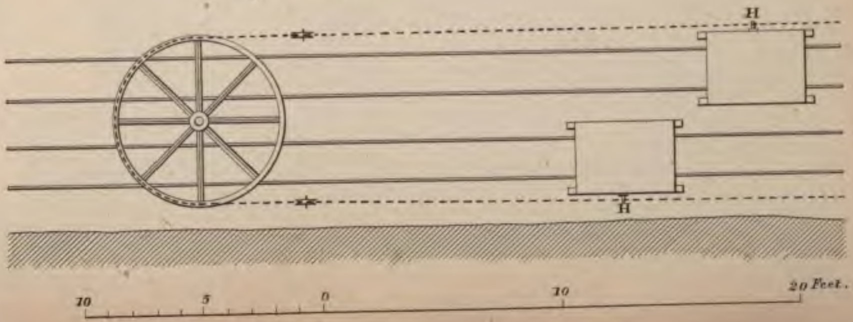
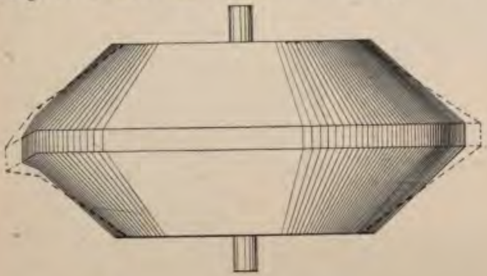


Fig. 8. *Plan of Conical Winding Drum.*



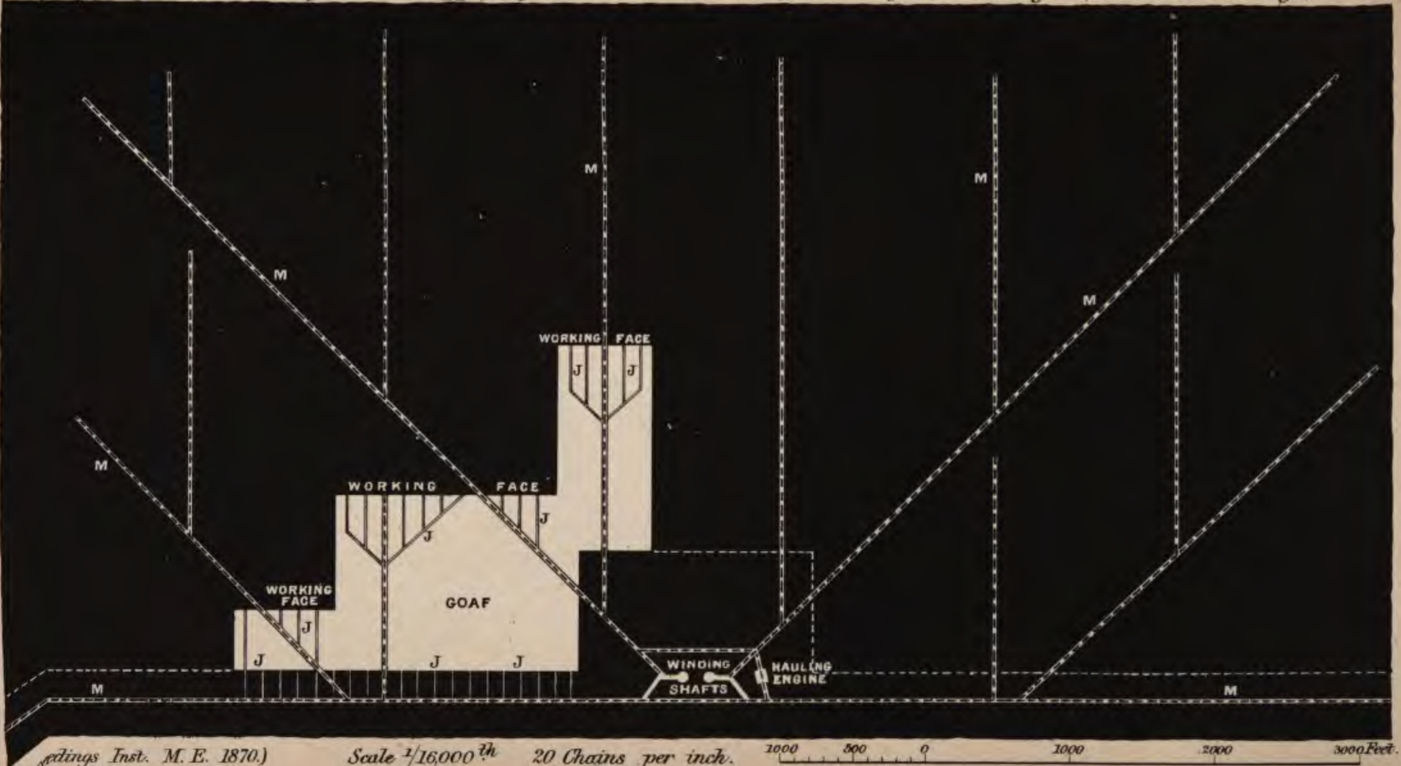
Scale 1/100th.

eedings Inst. M.E. 1870)

MIDLAND COLLIERY WORKING.

Plate 44.

Fig. 9. *Diagram showing mode of applying Endless Chain Haulage to Longwall Working. (Hucknall Colliery.)*



(Proceedings Inst. M. E. 1870.) *Scale 1/16,000th* *20 Chains per inch.*

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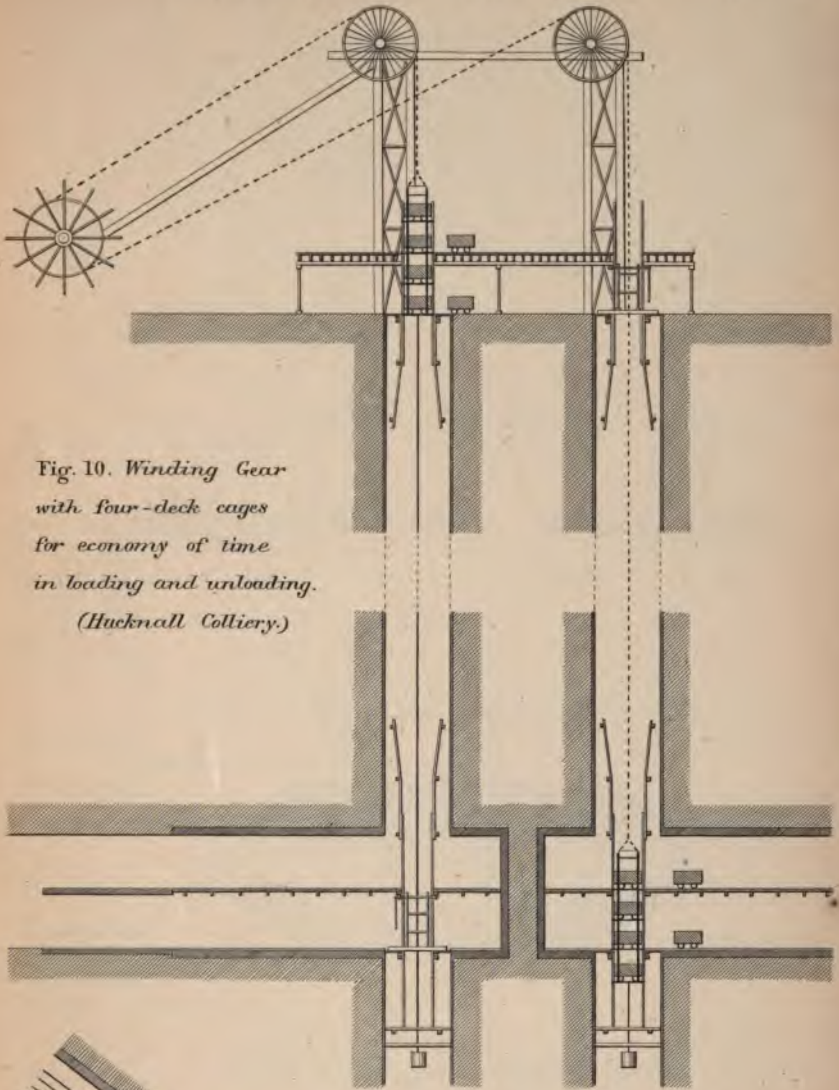

Fig. 10. *Winding Gear with four-deck cages for economy of time in loading and unloading. (Hucknall Colliery.)*

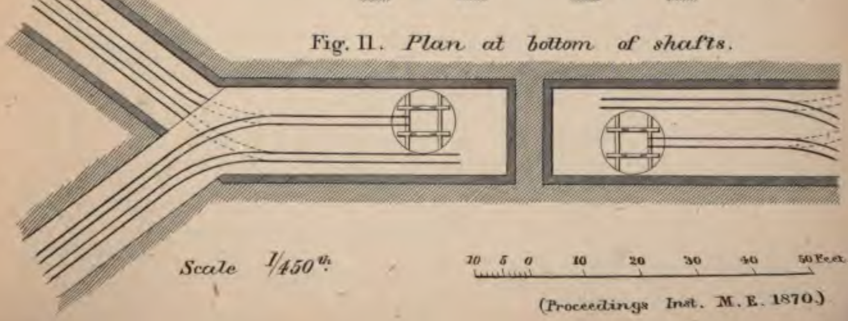

Fig. 11. *Plan at bottom of shafts.*

Scale 1/450th.

(Proceedings Inst. M.E. 1870.)

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MIDLAND COLLIERY WORKING.

Plate 46.

Diagrams of Colliery Winding Engines.

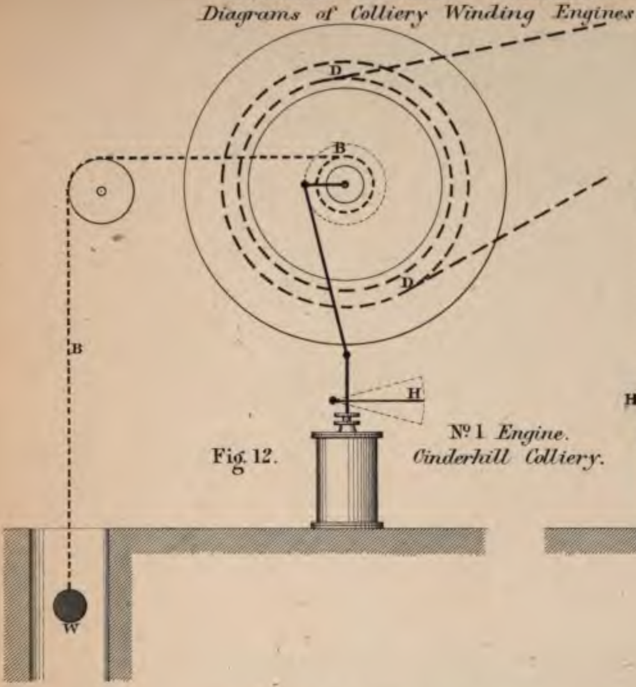


Fig. 12.

No 1 *Engine.*
Cinderhill Colliery.

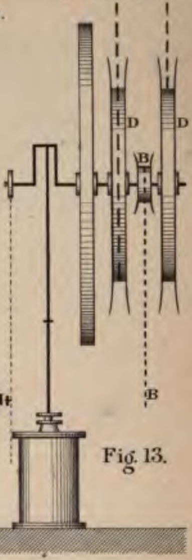


Fig. 13.

Fig. 14. No 2 *Engine. Kiveton Park Colliery.*

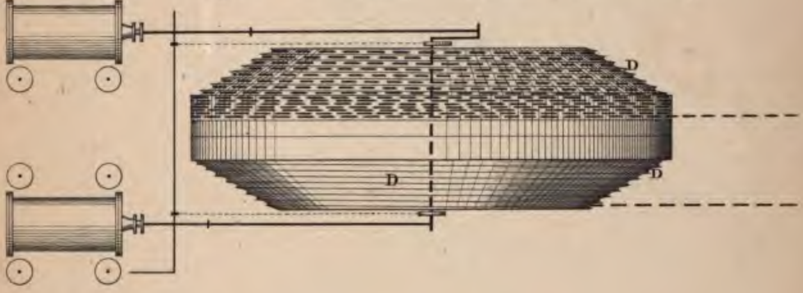
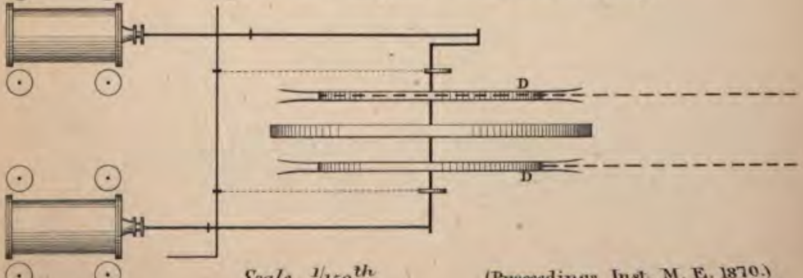
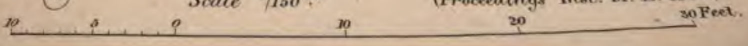


Fig. 15. No 3 *Engine. Hucknall Colliery.*



Scale 1/150th.

(Proceedings Inst. M. E. 1870.)



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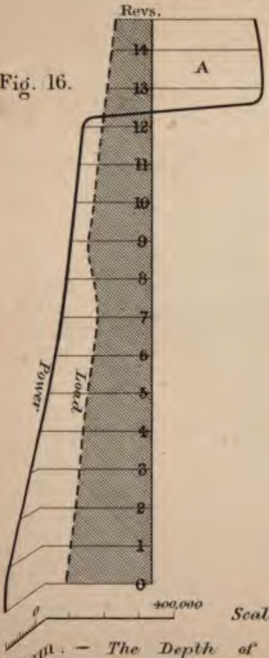
MIDLAND COLLIERY WORKING.

Diagrams showing Moments of Load and Power of Colliery Winding Engines.

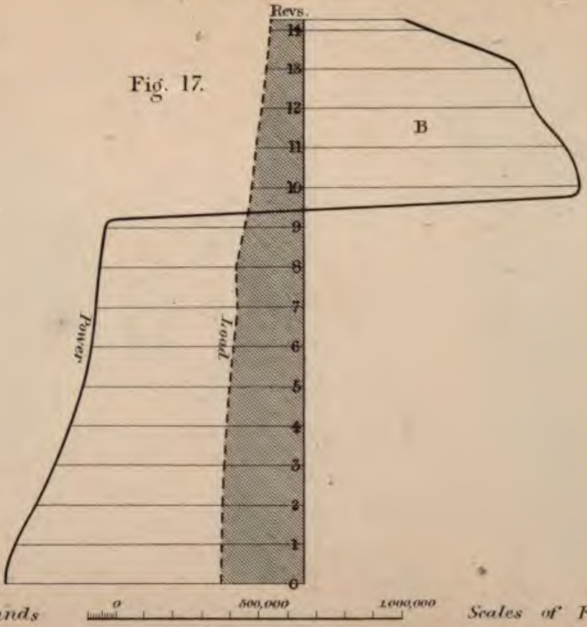
Nº 1 *Engine.*
Cinderhill Colliery.
222 *yards depth.*

Fig. 16.



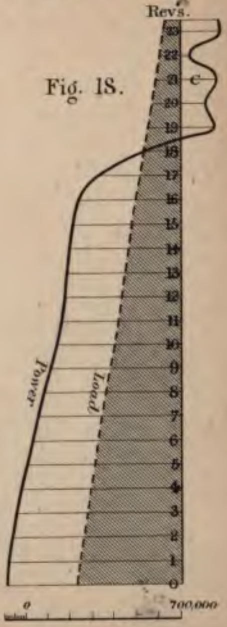
Nº 2 *Engine.*
Kiveton Park Colliery.
406 *yards depth.*

Fig. 17.



Nº 3 *Engine.*
Hucknall Colliery.
413 *yards depth.*

Fig. 18.



Scales of Foot-pounds *Scales of Foot-pounds*

Mem. – The Depth of Shaft and the area representing the Load are reduced to the same dimensions in each diagram for the purpose of comparison of the Engine Power.
(Proceedings Inst. M. E. 1870.)

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MIDLAND COLLIERY WORKING. *Plate 48.*

Indicator Diagrams from N.º 1 Winding Engine (Fig. 16.)
(Cinderhill Colliery.)

Fig. 19. *Diagrams taken in 1st, 7th, and 12th revolutions.*

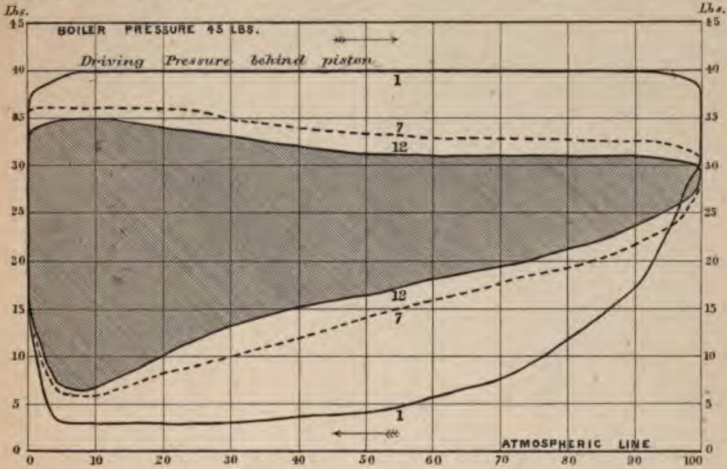
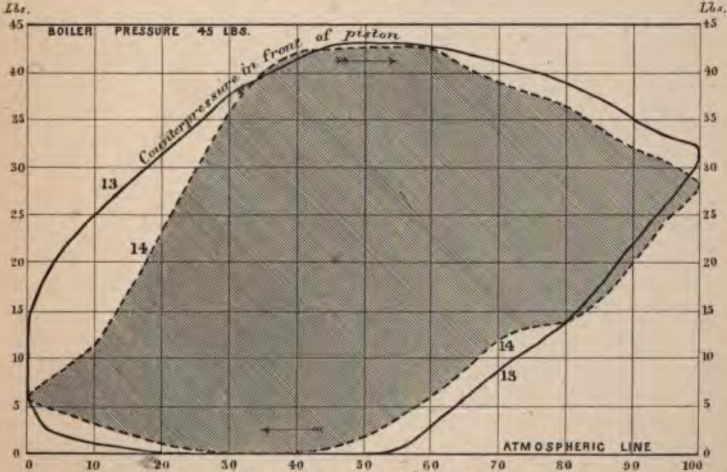


Fig. 20. *Counterpressure Diagrams taken in 13th and 14th revolutions,*
after reversing.
Valves worked by hand.



Percentage of Stroke.

Pressure above atmosphere, lbs. per square inch.

The arrows show the direction of motion of the piston.

(Proceedings Inst. M. E. 1870.)

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MIDLAND COLLIERY WORKING. *Plate 49.*

Indicator Diagrams from Nº 2 Winding Engine (*Fig. 17.*)
(Kiveton Park Colliery.)

Fig. 21. *Diagrams taken in 1st, 4th, and 9th revolutions.*

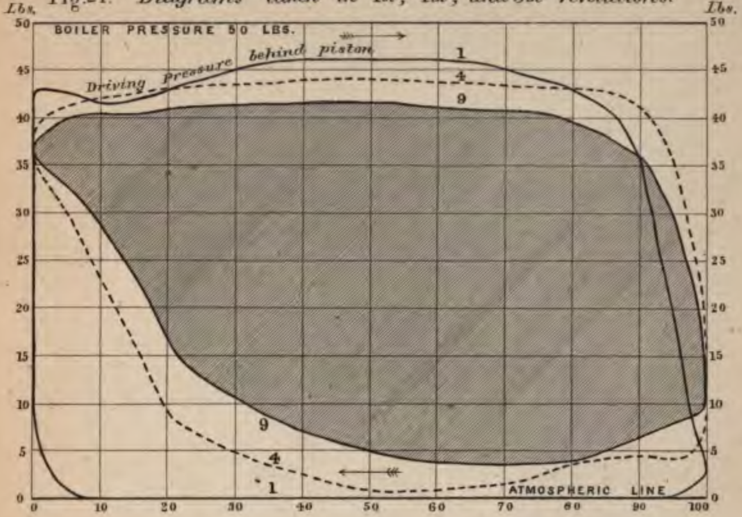
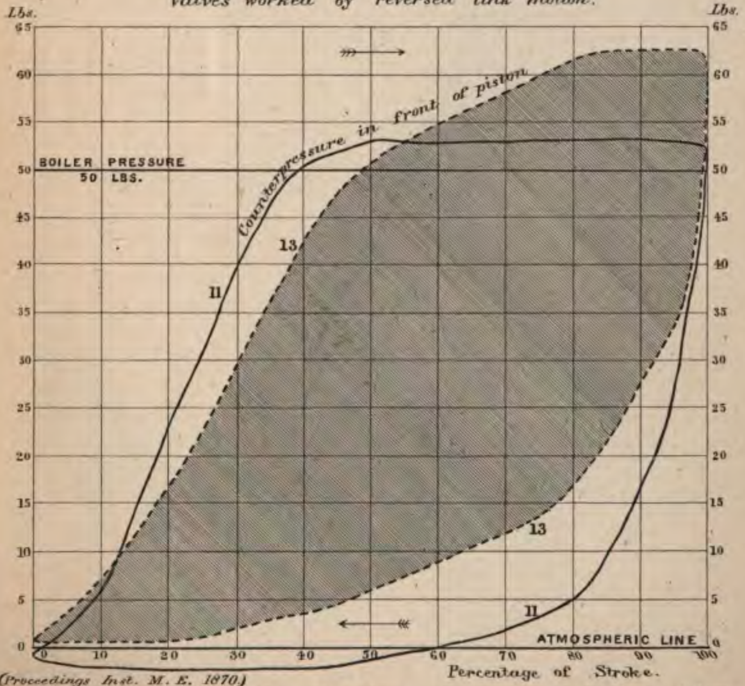


Fig. 22. *Counterpressure Diagrams taken in 11th, and 13th revolutions,* after reversing.
Valves worked by reversed link motion.



(Proceedings Inst. M. E. 1870.)

The arrows show the direction of motion of the piston.

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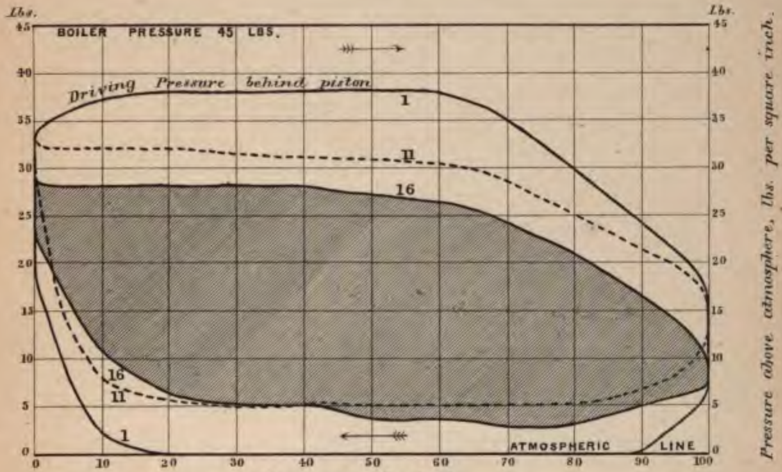
MIDLAND COLLIERY WORKING. *Plate 50.*

Indicator Diagrams from No. 3 Winding Engine (Fig. 18.)

(Hucknall Colliery.)

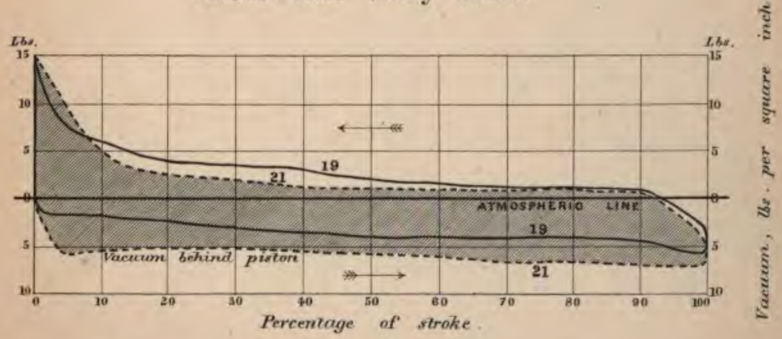
Fig. 23. *Diagrams taken in 1st, 11th, and 16th revolutions.*



Percentage of Stroke.

Fig. 24. *Vacuum Diagrams taken in 19th and 21st revolutions.*

Throttle-valve nearly closed.



Percentage of stroke.

The arrows show the direction of motion of the piston.

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Indicator Diagrams from Nº 3 Winding Engine (Fig. 18)

(Hucknall Colliery.)

Fig. 23. *Diagrams taken in 1st, 11th, and 16th revolutions.*

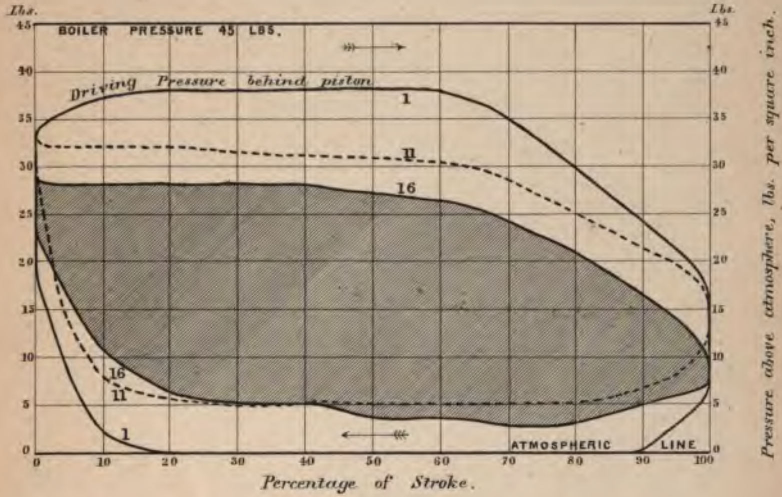
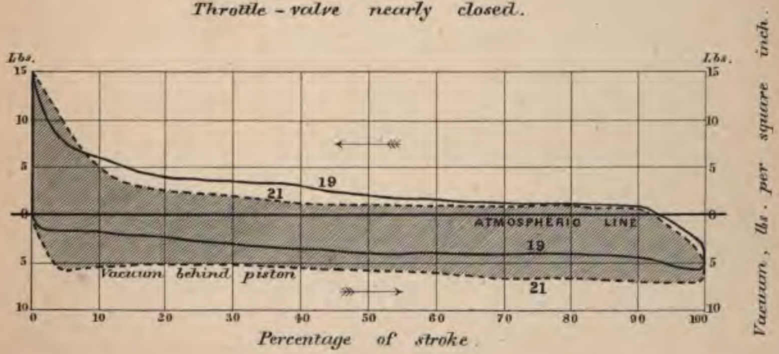


Fig. 24. *Vacuum Diagrams taken in 19th and 21st revolutions.*

Throttle-valve nearly closed.



The arrows show the direction of motion of the piston.

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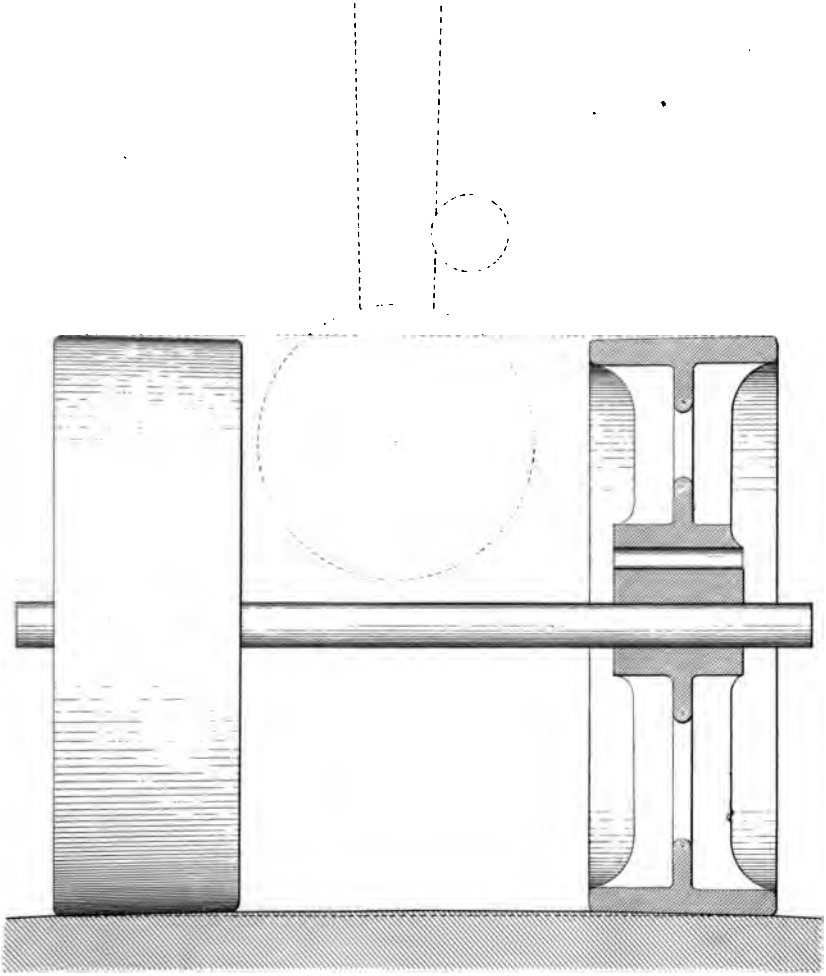
STEAM ROAD ROLLER.

Plate 51.

Three-Roller Machine, with Single-cylinder Engine.

End Elevation, showing one of Driving Rollers.



Scale 1/20th

(Proceedings Inst. M. E. 1870.)

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BOILER EXPLOSIONS. *Plate 52.*

Fig. 1. *Cornish Boiler; exploded from external corrosion.*
Length 22′ 4.″ Diam. 6′ 1.″ Southsea 1870.

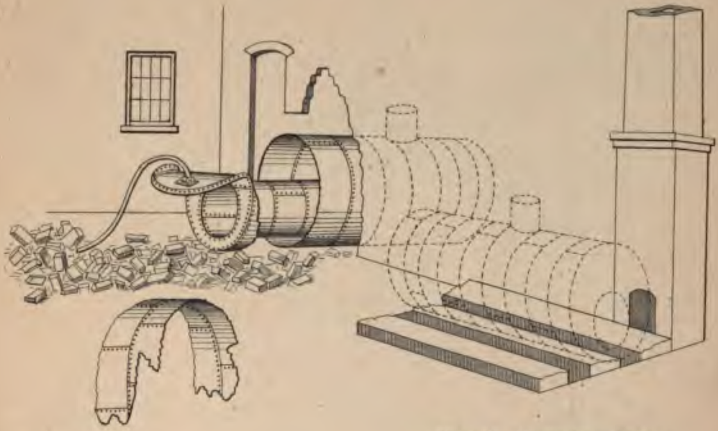


Fig. 2. *Lancashire Boiler,*
exploded from internal corrosion.
Length 32′ 0.″ Diam. 8′ 0.″
Manchester 1870.

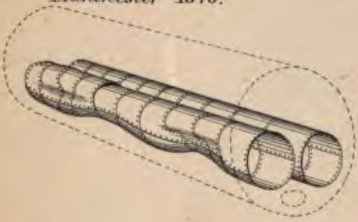


Fig. 4. *Cornish Boiler,*
exploded from external corrosion.
Length 14′ 6.″ Diam. 5′ 0.″
Accrington 1869.

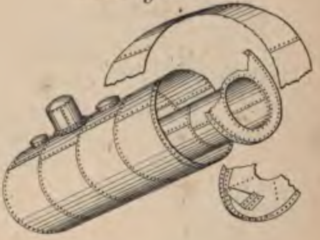


Fig. 3. *Lancashire Boiler;*
exploded from external corrosion.
Length 22′ 0.″ Diam. 7′ 6.″ Chatham 1866.

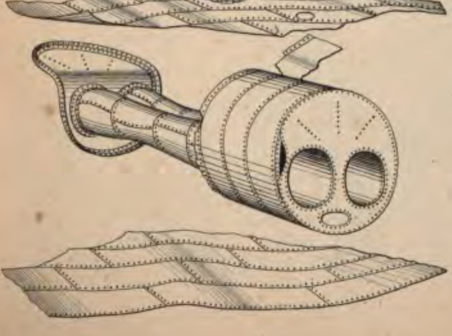
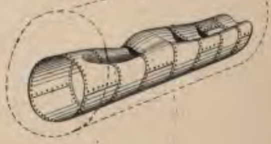


Fig. 5. *Cornish Boiler,*
exploded from internal corrosion.
Length 20′ 0.″ Diam. 6′ 0.″
Birmingham 1870.



(Proceedings Inst. M. E. 1870.)

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BOILER EXPLOSIONS.

Fig. 6. *Lancashire Boiler, externally fired, exploded from seam rip.*
Length 30′ 0″. Diam 7′ 0″. Tamworth 1867.

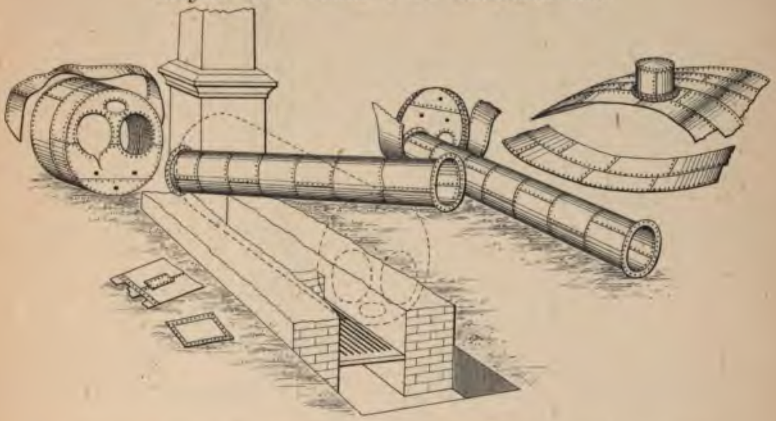
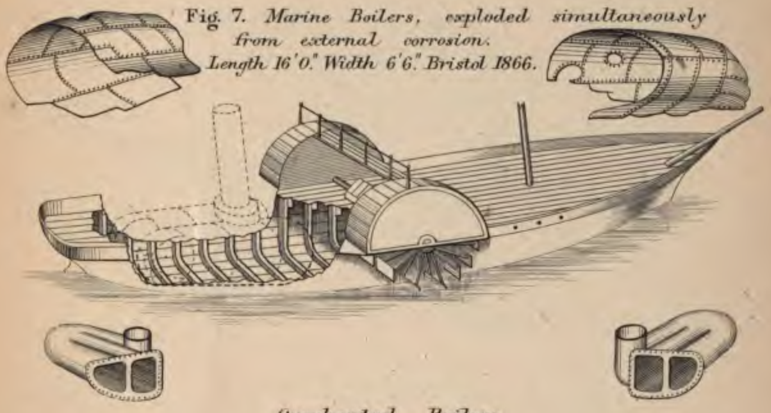


Fig. 7. *Marine Boilers, exploded simultaneously from external corrosion.*
Length 16′ 0″. Width 6′ 6″. Bristol 1866.



Overheated Boilers.

Fig. 8.
Plain Cylindrical.

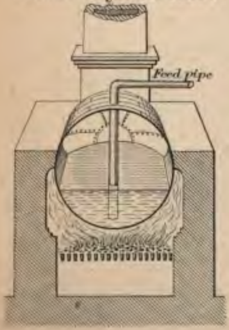


Fig. 9. *Furnace-Upright.*

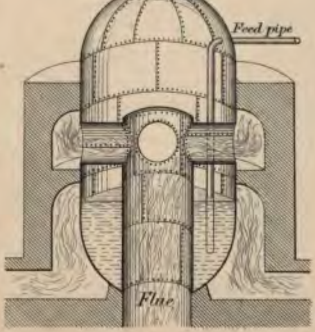
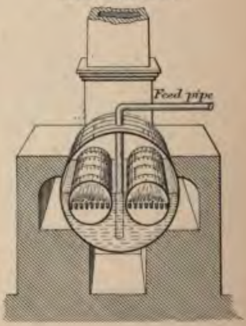


Fig. 10.
Lancashire.



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BOILER EXPLOSIONS.

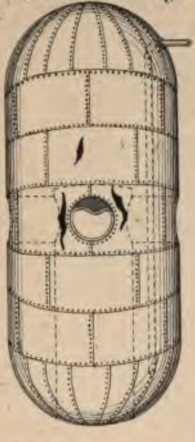
Plate 54.

Fig. 11. *Four-Furnace Upright Boiler*
Height 22′ 0.″ Diam. 9′ 0.″

Fig. 12. *Plain Cylindrical Boiler*
Length 25′6.″ Diam. 5′6.″

Exploded from softening of plates through shortness of water.

Stoke 1868.



Willenhall 1868.

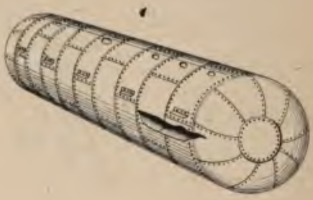


Fig. 13. *Revolving Rag Steamer,*
exploded from large weak manhole.
Length 16′ 0.″ Diam. 6′ 0.″ Abingdon 1869.

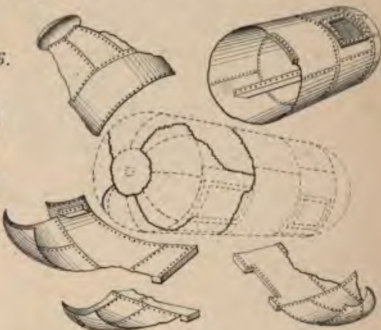


Fig. 14. *Revolving Rag Steamer,*
exploded from large weak manhole.
Length 12′ 6.″ Diam. 5′ 0.″ Tamworth 1866.

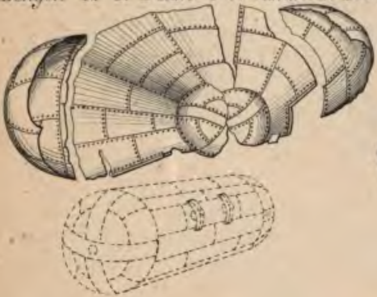


Fig. 15. *Plain Cyl. Boiler,*
exploded from frequent repair.
Length 40′0.″ Diam. 6′0.″
Greatbridge 1869.

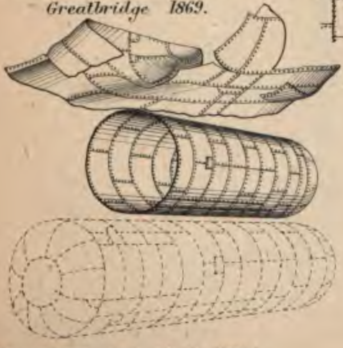
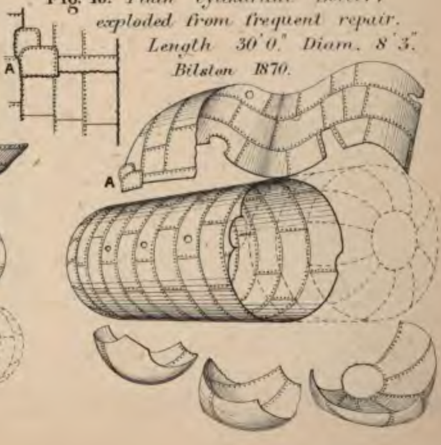


Fig. 16. *Plain Cylindrical Boiler,*
exploded from frequent repair.
Length 30′ 0.″ Diam. 8′ 3.″
Bilston 1870.



(Proceedings Inst. M. E. 1870.)

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Fig. 17. *Plain Cylindrical Boiler, exploded from frequent repair. Length 34' 0". Diam. 6' 0". Westbromwich 1870.*

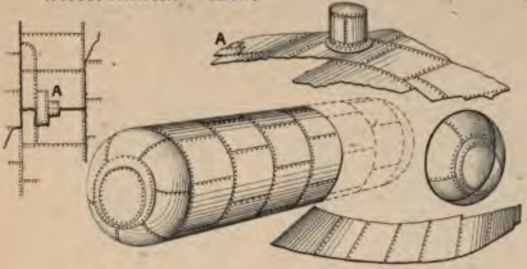

Fig. 18. *Plain Cylindrical Boiler, exploded from bad repair. Length 47' 0". Diam 6' 0". Durham 1869.*

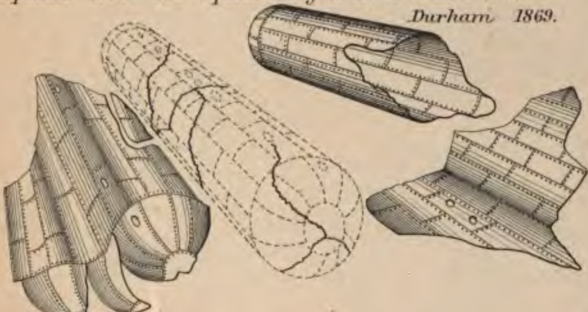

Fig. 19. *Two-Furnace Upright Boiler, exploded from external corrosion. Height 22' 0". Diam. 8' 10". Wrexham 1868.*

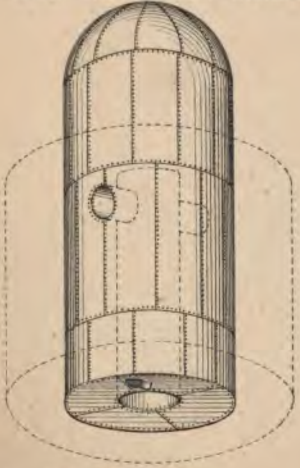

Fig. 20. *Chimney Boiler, exploded from internal corrosion. Height 41' 4". Diam. 6' 9". Liverpool 1868.*

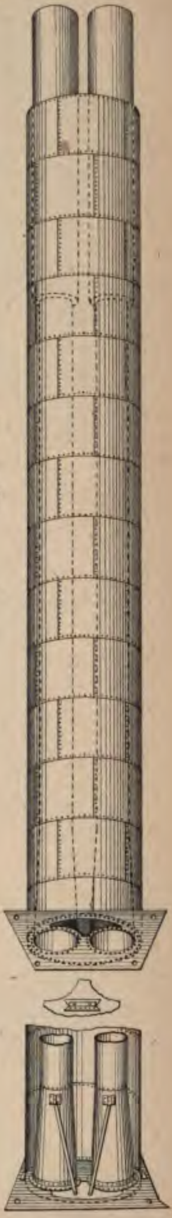

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Fig. 21. *Four-Furnace Upright Boiler, exploded from external corrosion of centre tube.*
Height 18′ 0″. Diam. 9′ 0″.
Tube 4′ 9″ diam. Kidsgrove 1870.

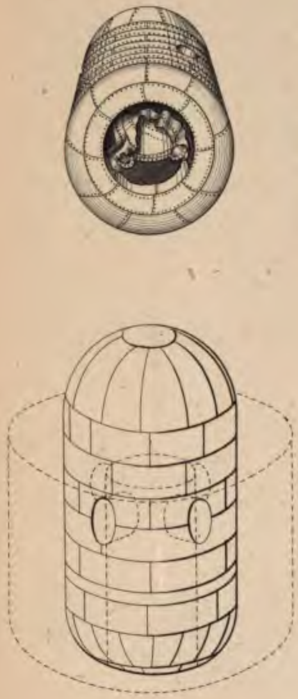


Fig. 22. *Four-Furnace Upright Boiler, exploded from internal corrosion of centre tube.*
Height 20′ 0″. Diam. 10′ 0″.
Tube 4′ 6″ diam. Bilston 1869.

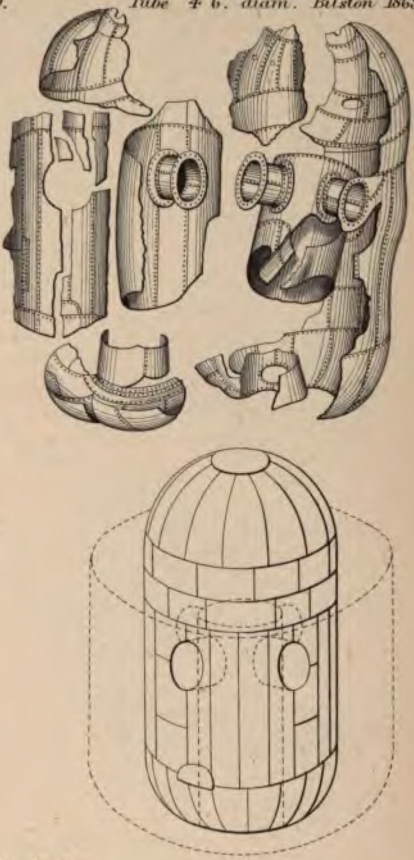
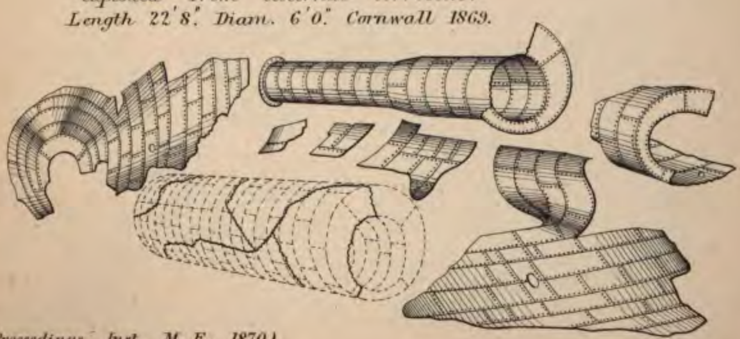


Fig. 23. *Cornish Boiler, exploded from external corrosion.*
Length 22′ 8″. Diam. 6′ 0″. Cornwall 1869.



(Proceedings Inst. M. E. 1870.)

BOILER EXPLOSIONS.

Fig. 24. *Four-Furnace Upright Boiler,*
exploded from seam rip.
Height 22' 0." Diam. 10' 6." Moxley 1868.

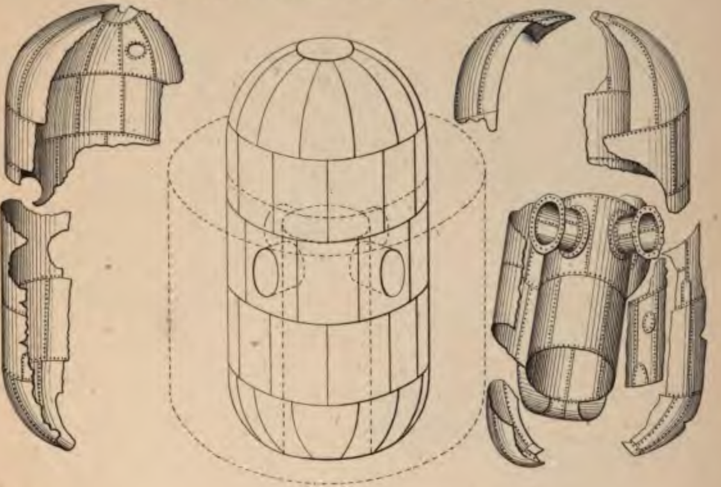


Fig. 25. *Cornish Boiler.*
Length 32' 0." Diam. 6' 6."
Tube 4' 0" diam. collapsed
from weakness. Cornwall 1869.

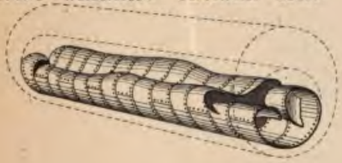


Fig. 27. *Cornish Boiler.*
Length 15' 0." Diam. 5' 0."
Tube oval at fire end,
2' 11" wide, 2' 6" high, collapsed
from weakness. London 1868.

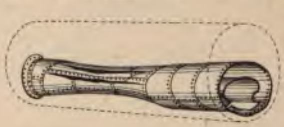


Fig. 26. *Cornish Boiler,*
exploded from screw patching.
Length 36' 0." Diam. 7' 0." Tube 3' 10" diam. Cornwall 1869.

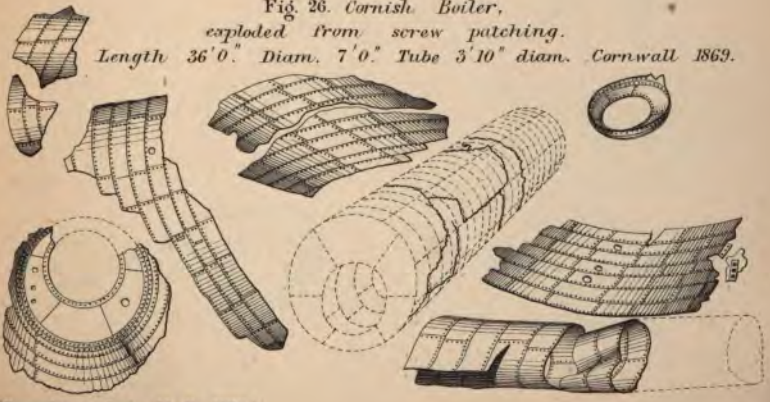


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Fig. 28. *Vertical Crane Boiler,*
exploded from external corrosion.
Height 8' 3." Diam. 4' 4."
Firebox 6' 0" high, 3' 6" diam.
Barking 1869.

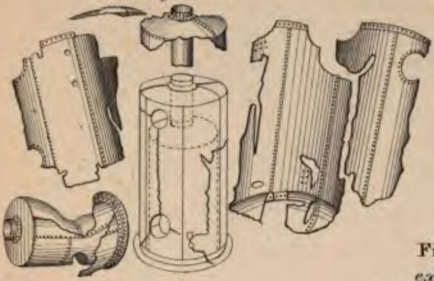


Fig. 29. *Vertical Crane Boiler,*
exploded from bad manhole.
Height 5' 6." Diam. 2' 6."
Liverpool 1866.

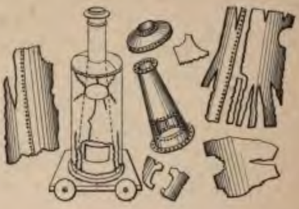


Fig. 30. *Portable Boiler,*
exploded from bad manhole.
Height 4' 9." Diam. 2' 3."
Birmingham 1868.

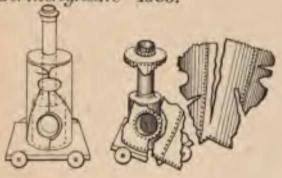


Fig. 31. *Multitubular Boiler,*
exploded from bad manhole.
Length 8' 6." Barrel 6' 0" long, 2' 4" diam.
Broseley 1869.

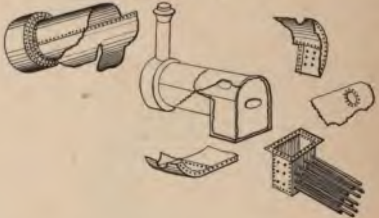


Fig. 32. *Elbow Boiler, exploded from ends bulging through absence of stays.*
Length 22' 0." Diam. 5' 0." Tube 2' 0" diam. Bilston 1868.

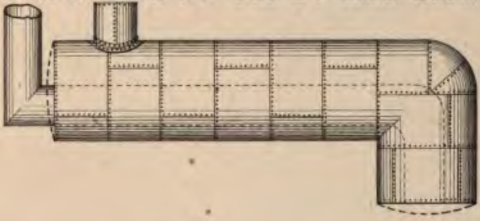


Fig. 33. *Plain Cylindrical Boiler*
altered from Breeches-Tube,
exploded from absence of stays.
Length 36' 0." Diam. 6' 0."
Lydney 1869.

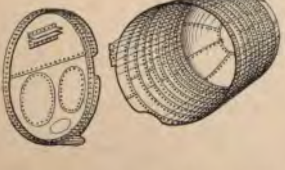
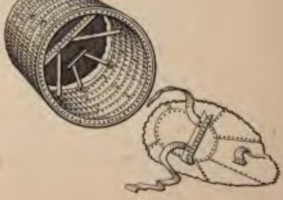


Fig. 34. *Plain Cylindrical Boiler*
altered from Cornish,
exploded from insufficient stays.
Length 25' 0." Diam. 6' 0."
Dudley 1867.



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BOILER EXPLOSIONS.

Plate 59.

Fig. 35. *Plain Cylindrical Boiler, exploded from external corrosion.*
Length 21′ 0″ Diam. 4′ 6″
Kidderminster 1869

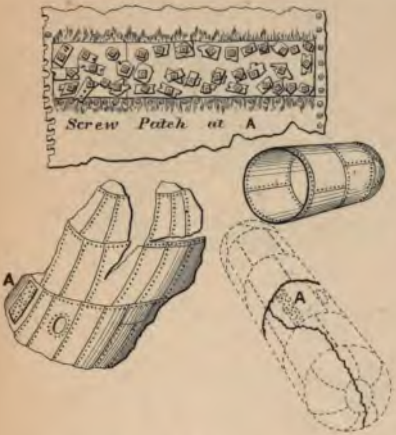


Fig. 36. *Plain Cylindrical Boiler, exploded from frequent repair.*
Length 25′ 0″ Diam. 4′ 6″
Westbromwich 1869.

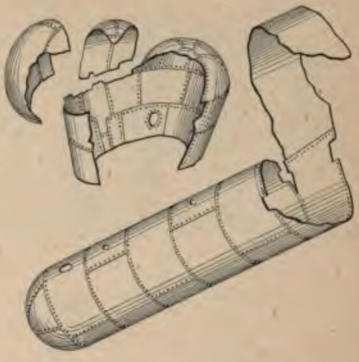


Fig. 37. *Furnace-Upright Boiler. Flat crown-plate to inside tube.*

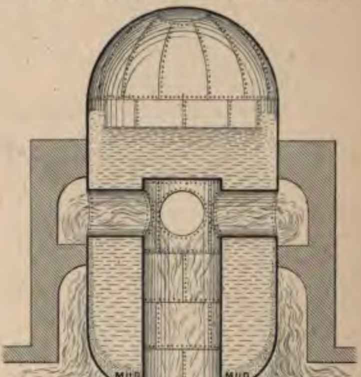


Fig. 38.
Plate injured by overheating.

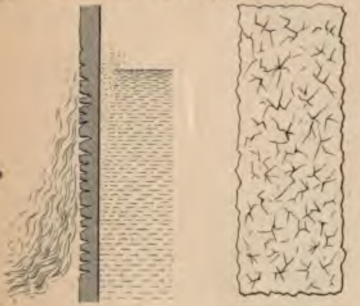
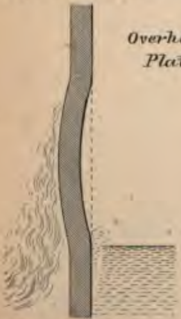


Fig. 39. *No water.*



Overheated Plates.

Fig. 40. *Water not in contact.*

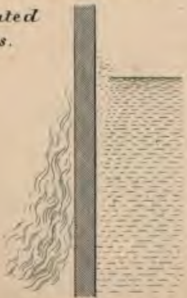


Fig. 41. *Cornish Boiler overheated, water not in contact.*

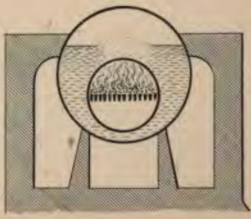


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Fig. 42. *Plain Cylindrical Boiler, easy to examine.*

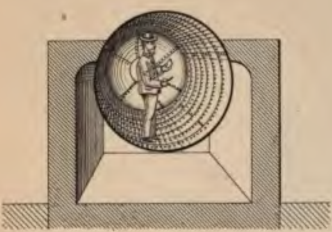
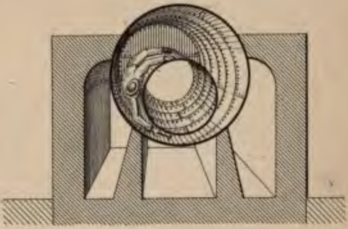


Fig. 43. *Cornish Boiler, awkward to examine.*



Lancashire Boiler with Narrow Flues.

Fig. 44.

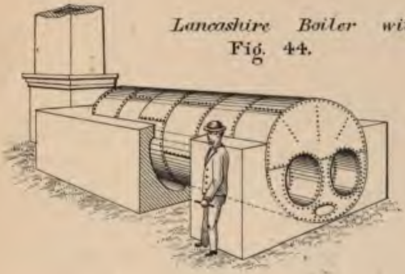
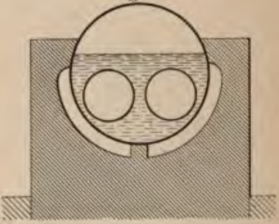


Fig. 45.



Lancashire Boilers.

Fig. 46. *Wide Flues.*

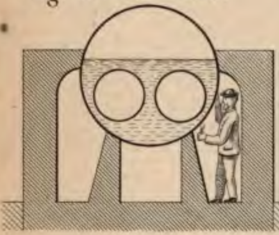


Fig. 47. *Wide Flues.*

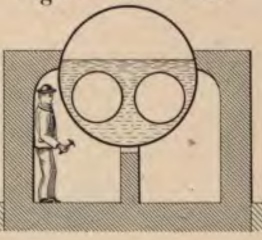
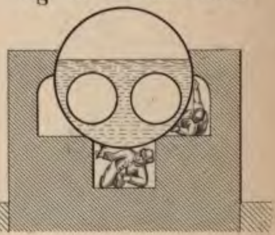


Fig. 48. *Narrow Flues.*



Cornish Boiler, with sight-holes in flues.

Fig. 49.

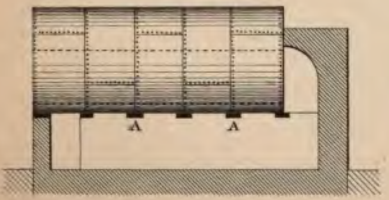
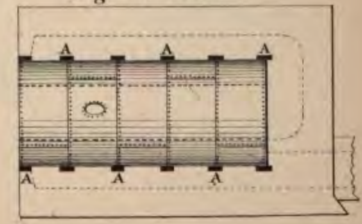


Fig. 50. *Plan.*



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BOILER EXPLOSIONS.

Plate 61.

Fig. 51. *Domestic Boiler, exploded from weak shape.*
3'6" x 2'6" x 1'0".
London 1868.

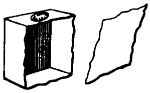


Fig. 55. *Safe Domestic Boiler.*

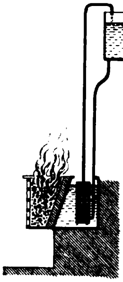


Fig. 52. *Domestic Boiler, exploded from overpressure.*
12" x 12" x 13".
Derby 1870.

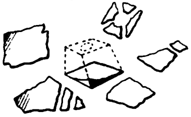


Fig. 53. *Domestic Boiler, exploded from overpressure.*
14" x 11" x 10". Manchester 1869.

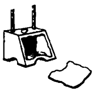


Fig. 54. *Domestic Boiler, exploded from bad weld.*
2'6" x 2'0" x 1'1". Sheffield 1870.

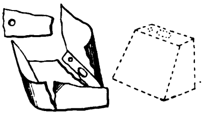


Fig. 56. *Multitubular Boiler, exploded from overpressure, safety-valve tied down.*
Length 6'0" Diam. 2'0".
Lynn 1867.

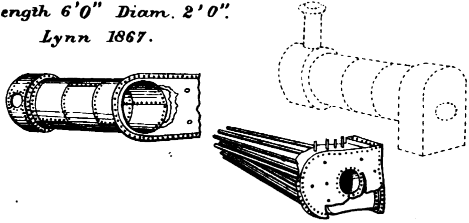


Fig. 58. *Scale and Mud.*

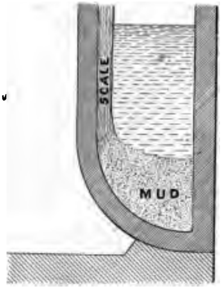


Fig. 57. *Marine Boiler, exploded from corrosion.*
Length 17'0" Height 15'0".
Yarmouth 1869.

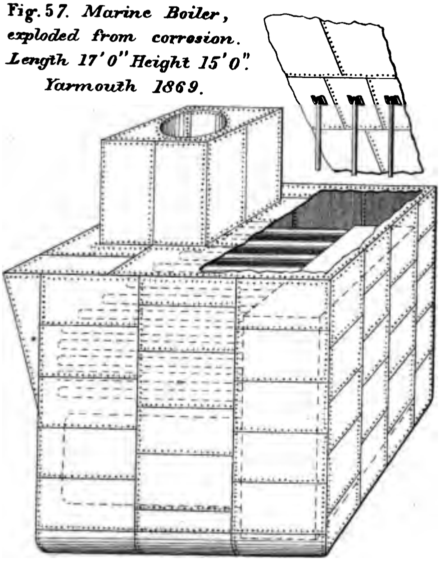
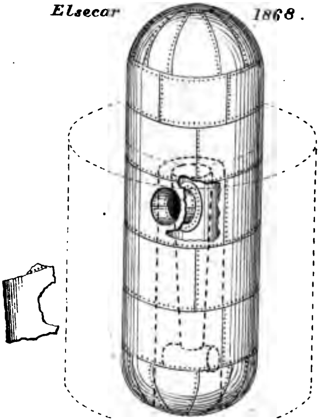


Fig. 59.
Two-Furnace Upright Boiler, exploded from intense flame.
Height 21'0" Diam. 7'0".
Elsecar 1868.



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SAFETY VALVE.

Combined External Safety Valve and Fire-Extinguishing Valve applied to Lancashire Boiler.

Fig. 1. *Transverse Section.*

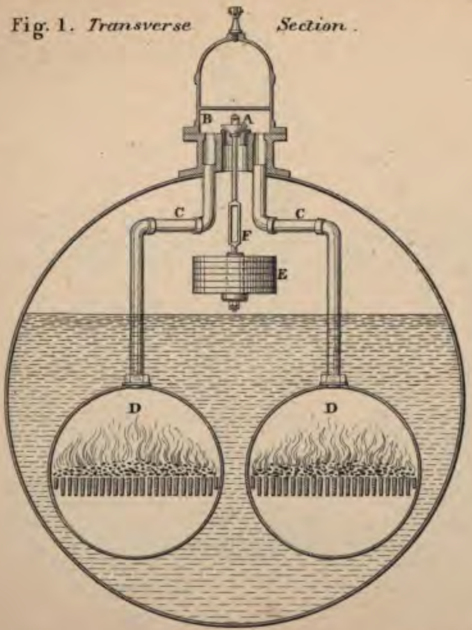
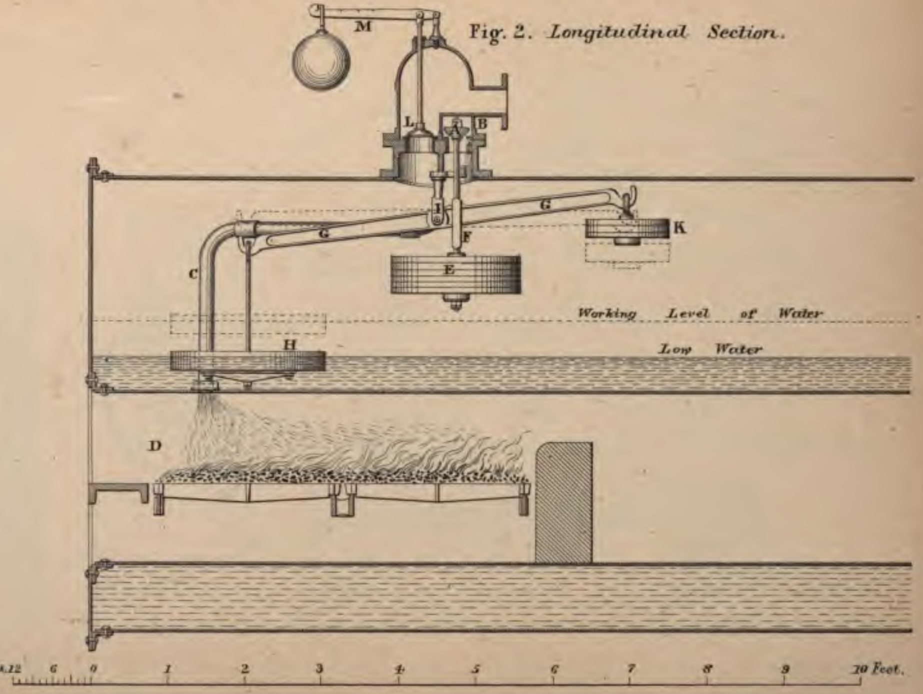


Fig. 2. *Longitudinal Section.*



(Proceedings Inst. M.E. 1870.)

Scale $1/30^{th}$.

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SAFETY VALVE.

Plate 63.

Single External Safety and Fire-Extinguishing Valve applied to Plain Cylindrical Boiler.

Fig. 3. *Transverse Section.*

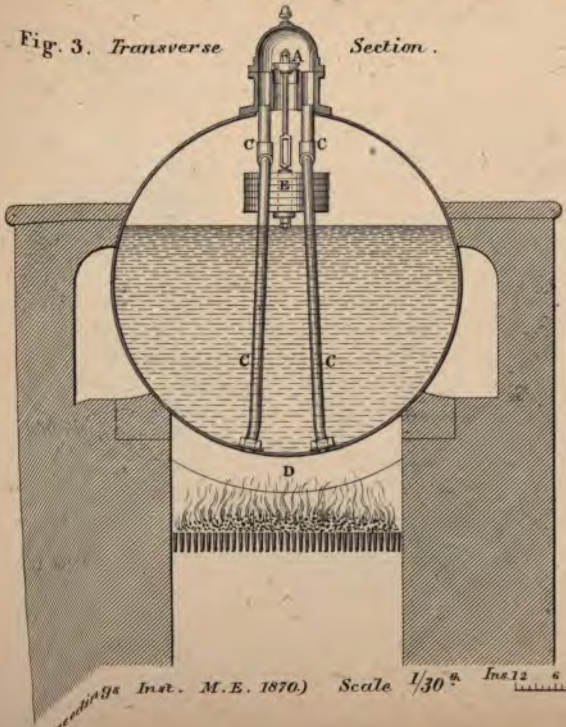
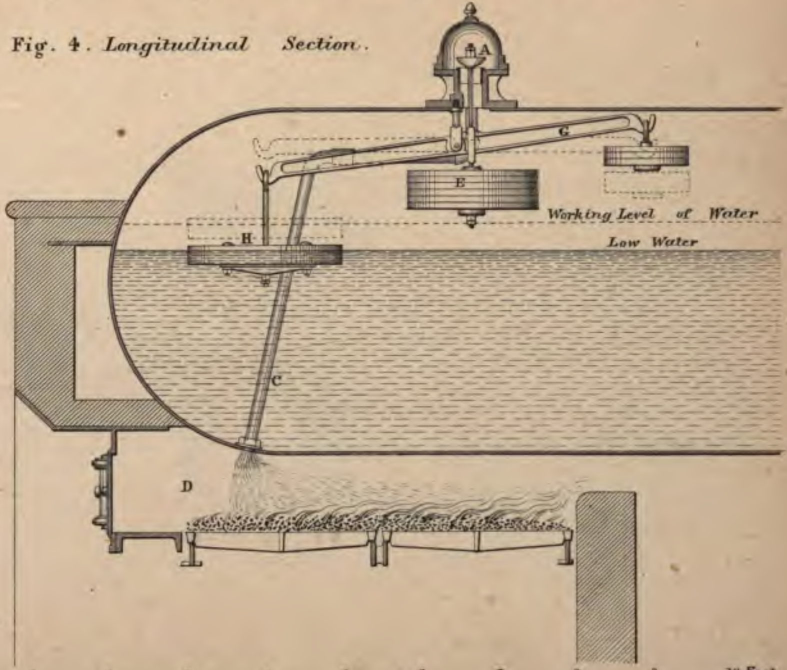


Fig. 4. *Longitudinal Section.*



(Proceedings Inst. M.E. 1870.) *Scale* 1/30th

SAFETY VALVE.

Single Internal Safety Valve and Fire-Extinguishing Valve.

Fig 5. Transverse Section.

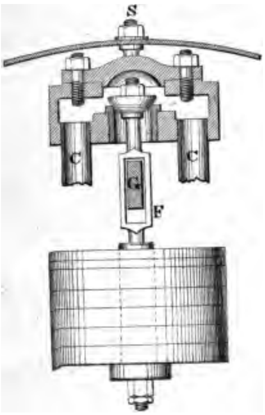
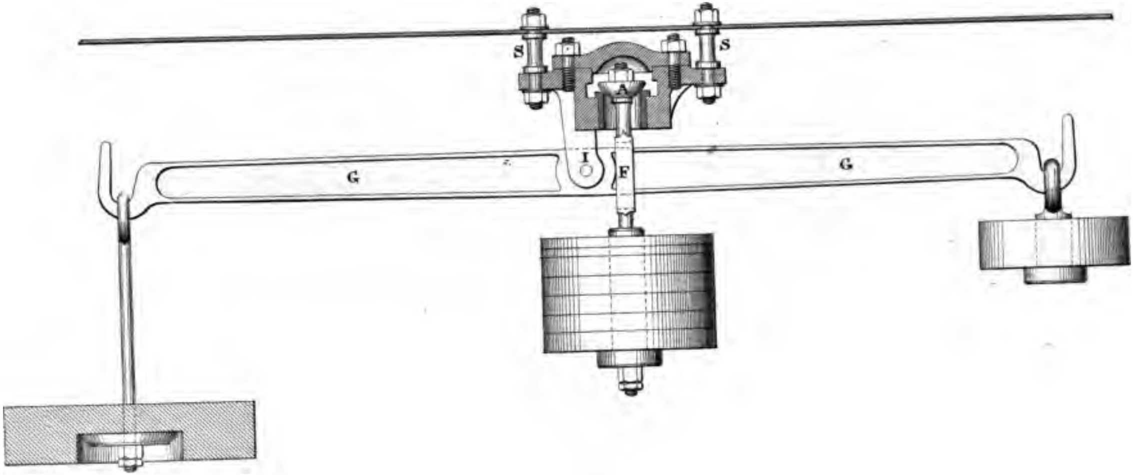
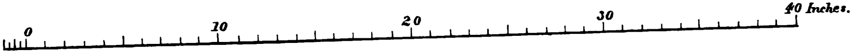


Fig. 6. Longitudinal Section.



Scale 1/10th.



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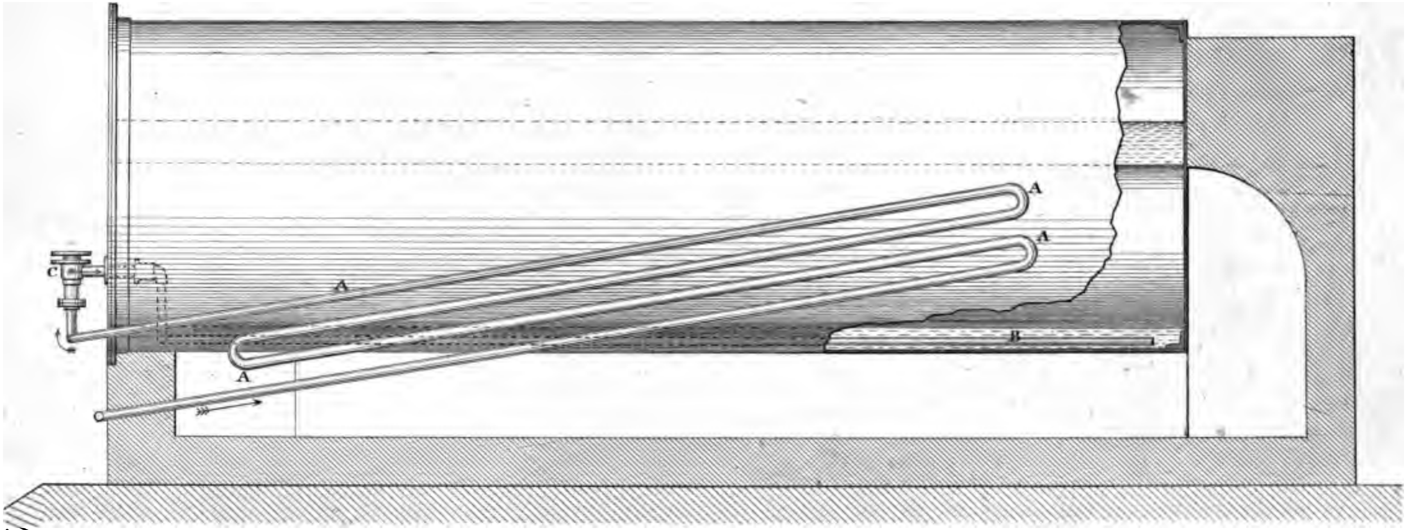
WARSOP AERO-STEAM ENGINE.

Ordinary Stationary Boiler.

Fig. 1. *Longitudinal Section.*



Scale 1/40th

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SAFETY VALVE.

Combined External Safety Valve and Fire-Extinguishing Valve applied to Lancashire Boiler.

Fig. 1. *Transverse Section.*

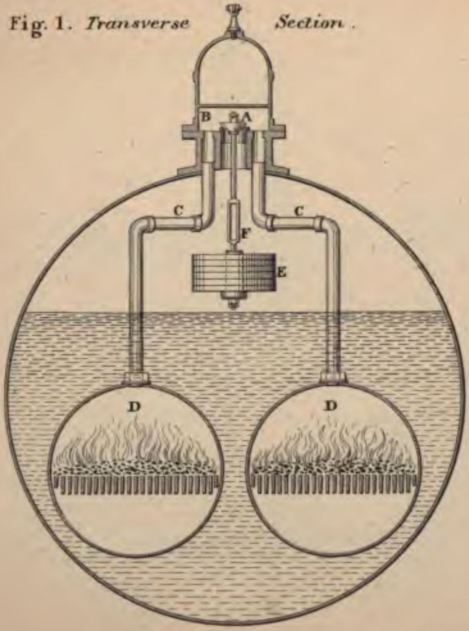
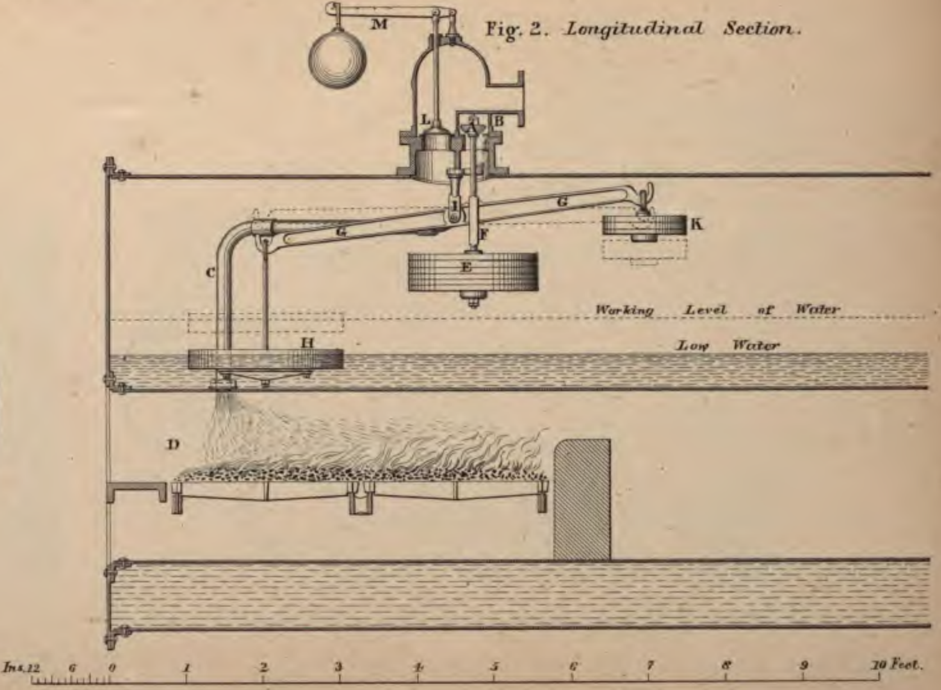


Fig. 2. *Longitudinal Section.*



(Proceedings Inst. M.E. 1870.)

Scale 1/30th.

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SAFETY VALVE.

Single External Safety and Fire-Extinguishing Valve applied to Plain Cylindrical Boiler.

Fig. 3. *Transverse Section.*

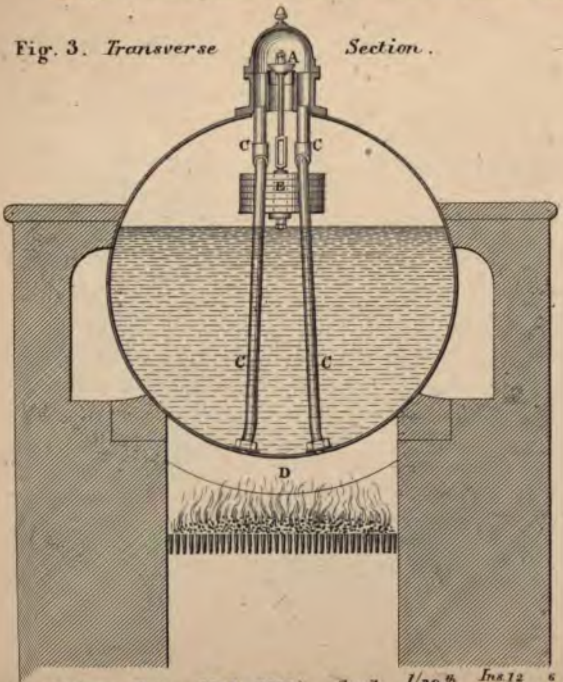
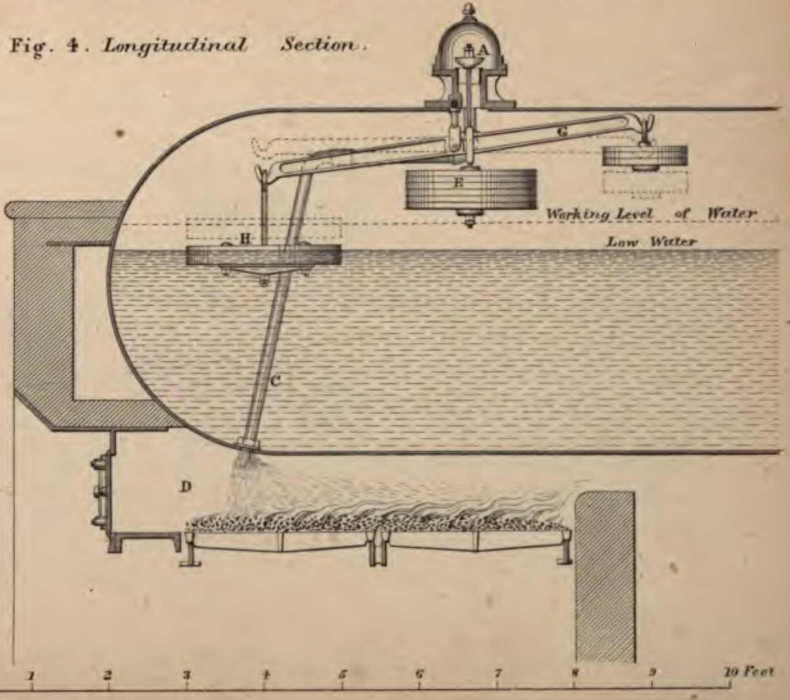


Fig. 4. *Longitudinal Section.*



(Proceedings Inst. M.E. 1870) *Scale 1/30th.*

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SAFETY VALVE.

Single Internal Safety Valve and Fire-Extinguishing Valve.

Fig 5. *Transverse Section.*

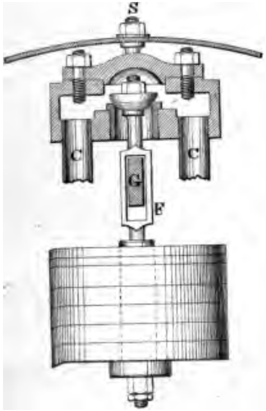
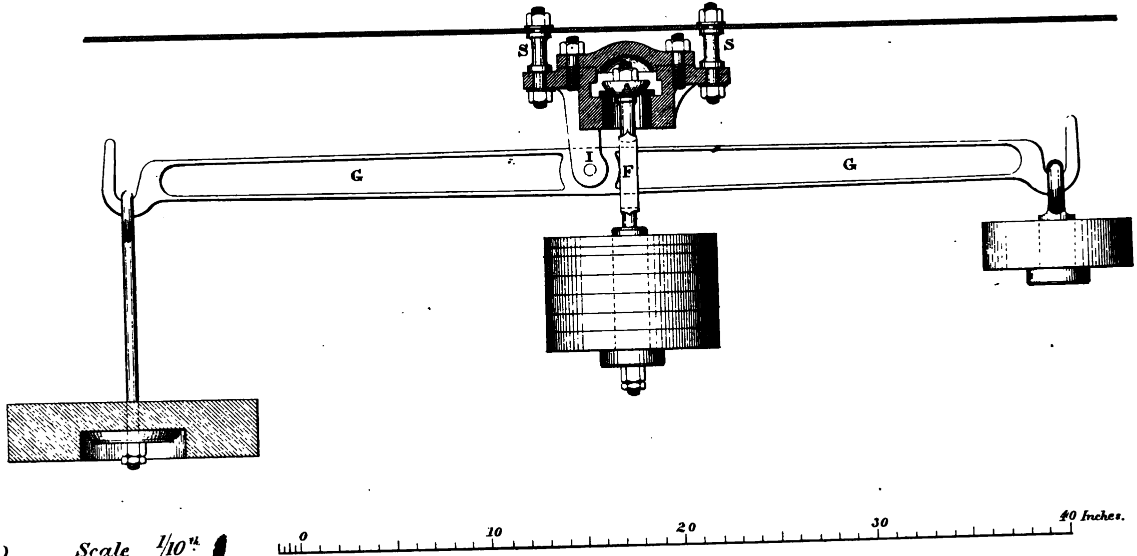


Fig. 6. *Longitudinal Section.*



Scale 1/10th.

(Proceedings Inst. M. E. 1870.)

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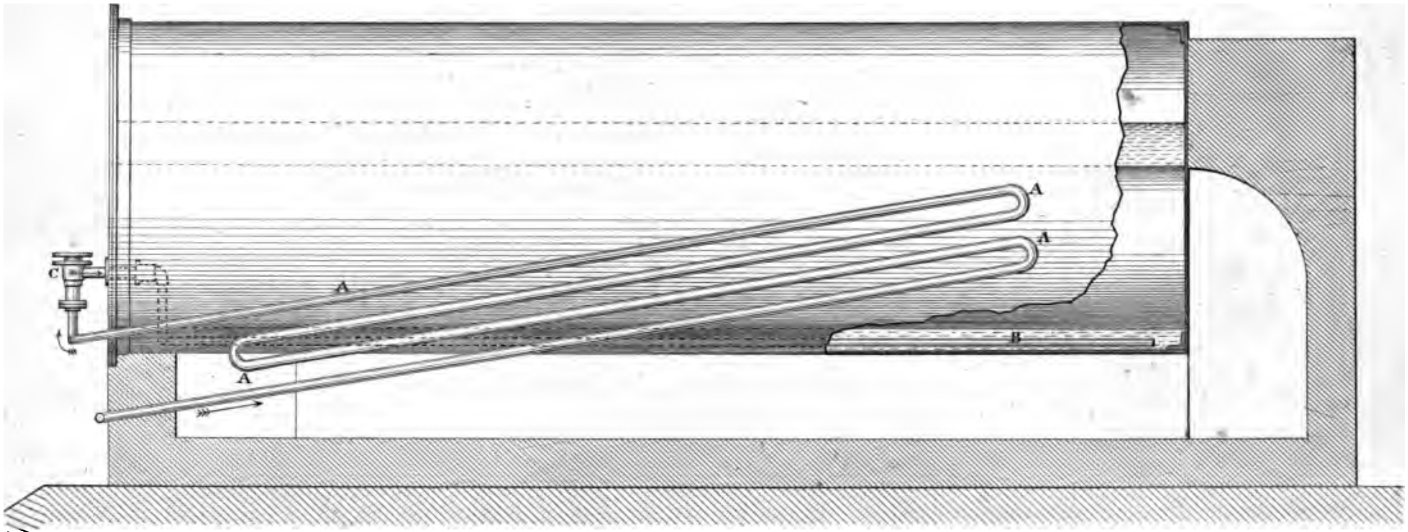
WARSOP AERO-STEAM ENGINE.

Ordinary Stationary Boiler.

Fig. 1. *Longitudinal Section.*



Scale $1/40$th

(Proceedings Inst. M. E. 1870.)

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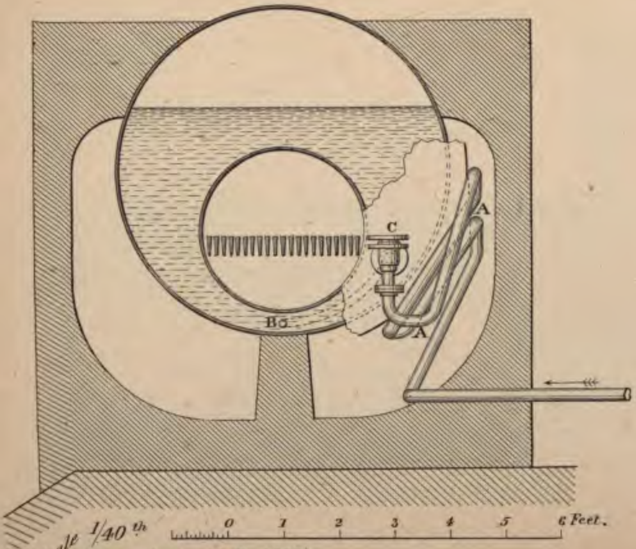
WARSOP AERO-STEAM ENGINE.

Plate 66.

Ordinary Stationary Boiler.

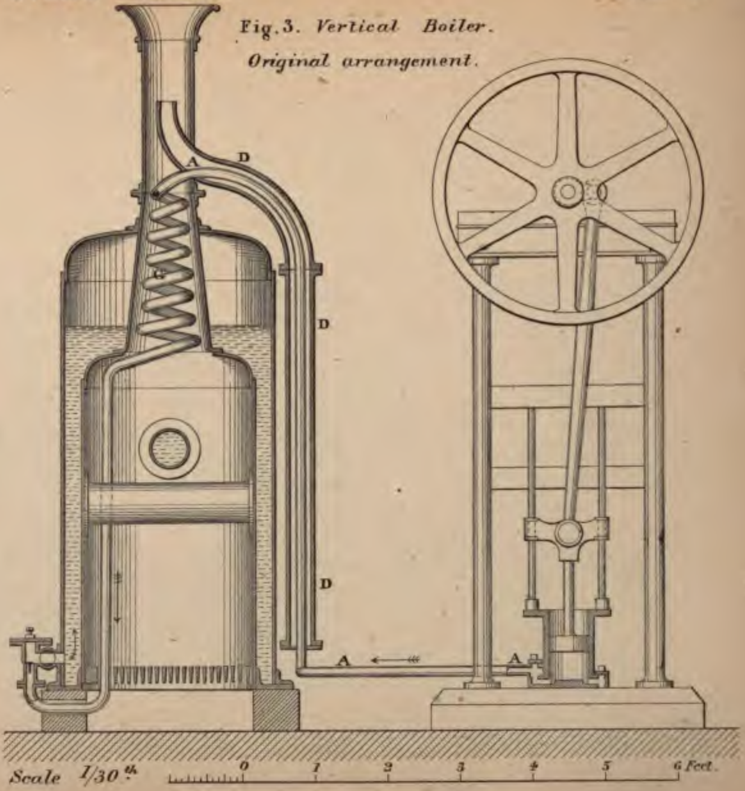
Fig. 2. Transverse Section.



(Proceedings Inst. M. E. 1870)

Fig. 3. Vertical Boiler.

Original arrangement.



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WARSOP AERO-STEAM ENGINE.

Plate 67.

Experimental Boiler.

Fig. 4. *Longitudinal Section.*

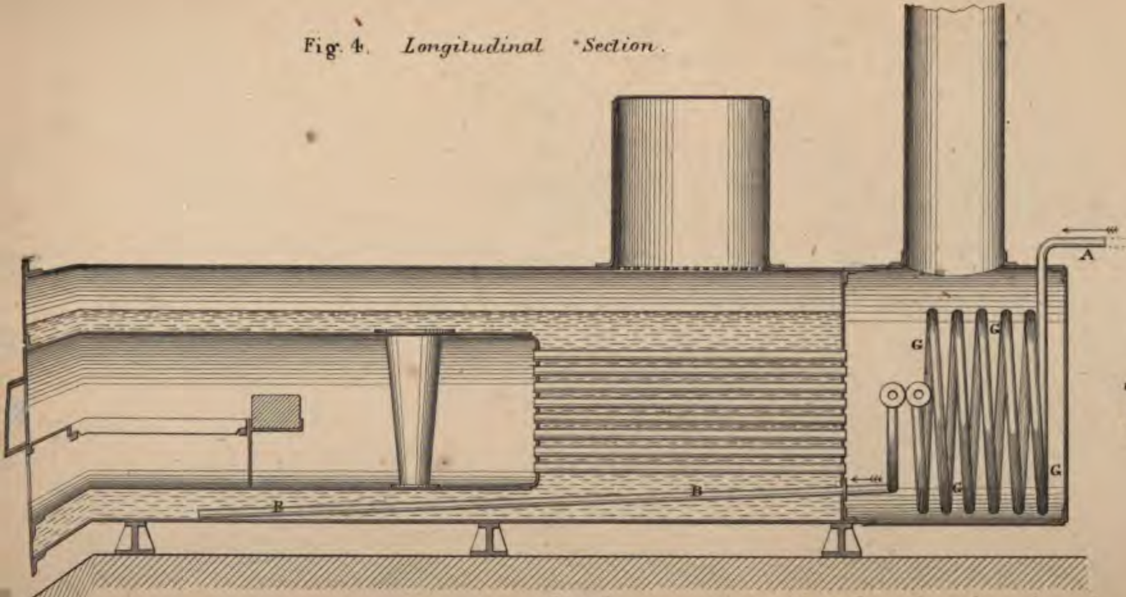
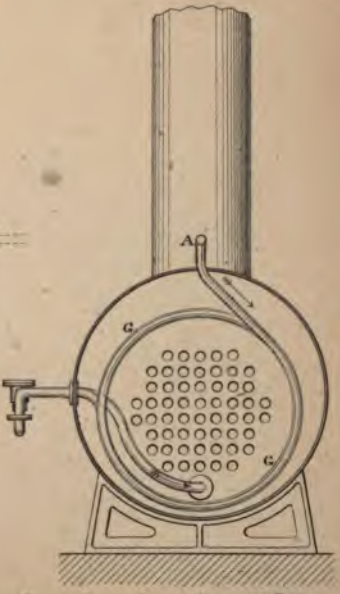


Fig. 5. *Transverse Section through smokebox.*



Scale 1/40th.

0 1 2 3 4 5 6 7 8 9 10 Feet

(Proceedings Inst. M. E. 1870.)

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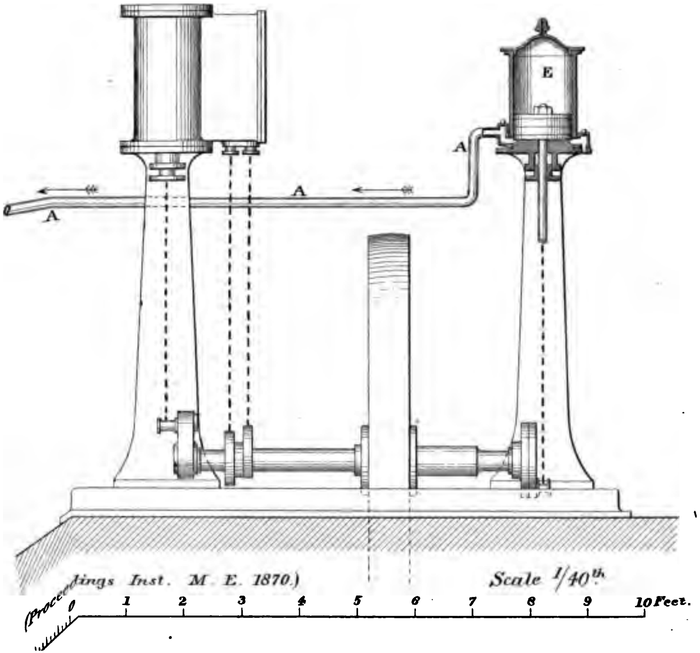
WARSOP AERO-STEAM ENGINE.

Experimental Engine.

Fig. 6. *Elevation of Engine.*



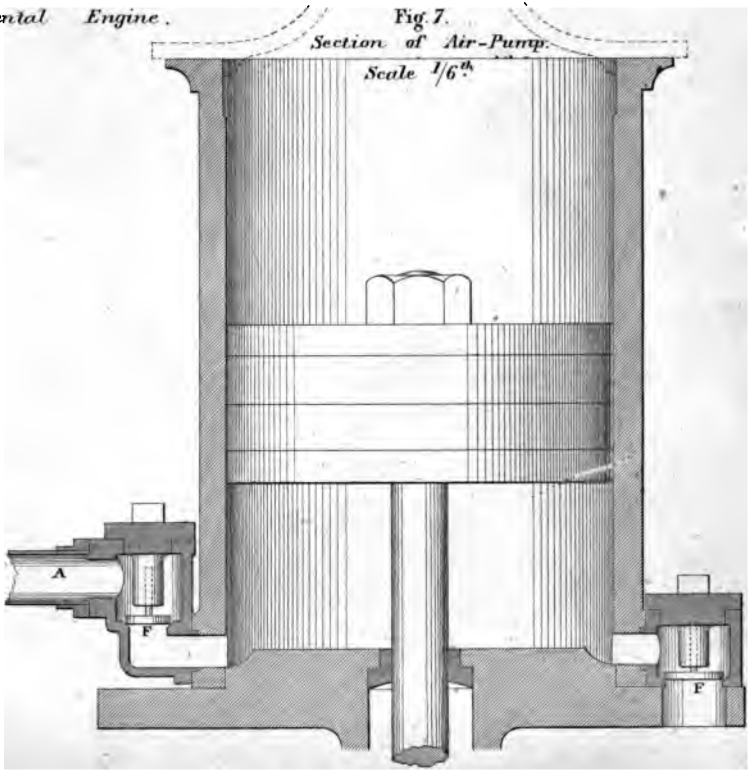
Scale 1/40th.

(Proceedings Inst. M. E. 1870.)

Fig. 7.

Section of Air-Pump.

Scale 1/6th.



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WARSOP AERO-STEAM ENGINE.

Marine Boiler, "Fuh-le" Steamer.

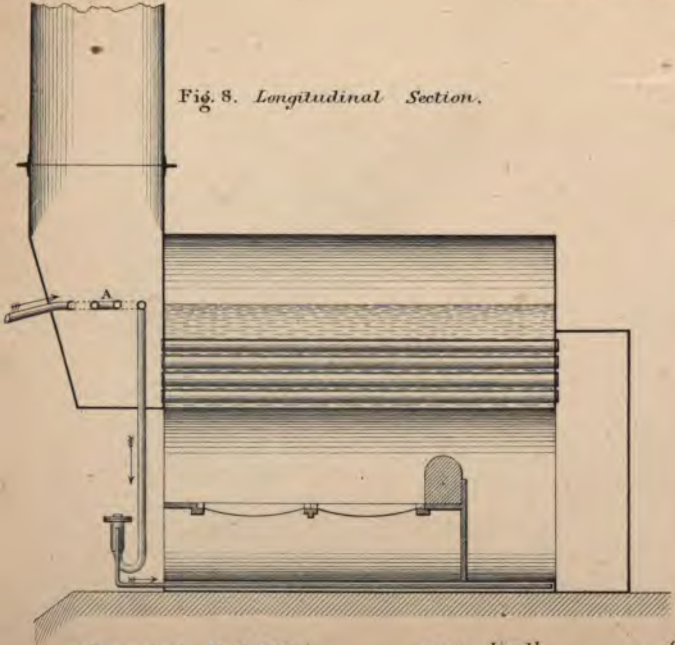

Fig. 8. *Longitudinal Section.*

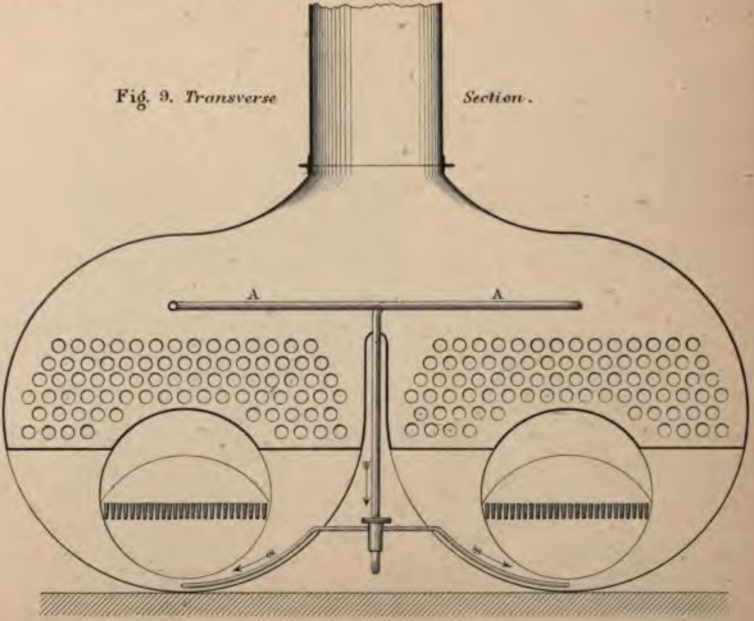

Fig. 9. *Transverse Section.*

Scale 1/50 th

(Proceedings Inst. M. E. 1870.)

WARSOP AERO-STEAM ENGINE. *Plate 70.*

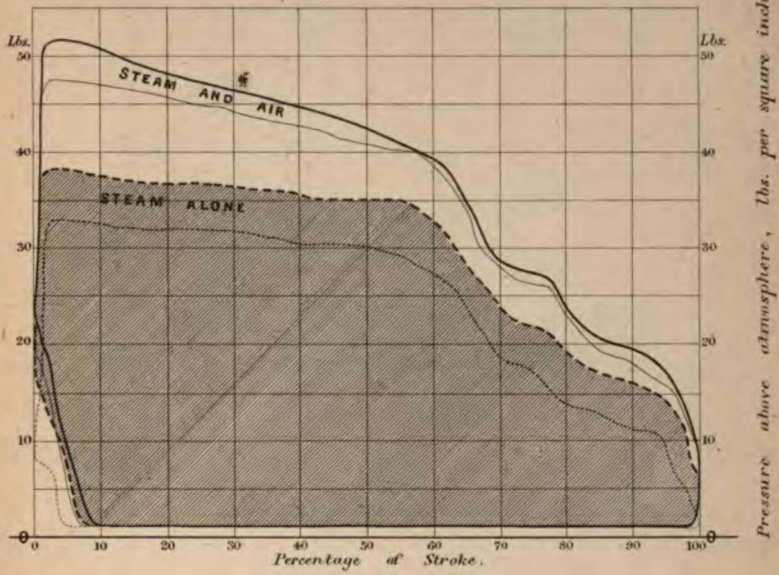
Fig. 10. *Indicator Diagrams from Non-condensing Engine.*

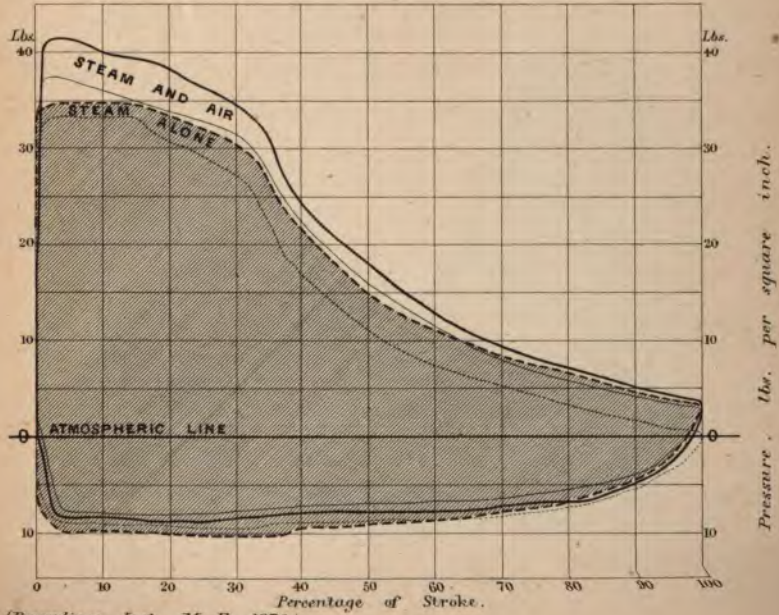
Fig. 11. *Indicator Diagrams from Condensing Engine.*

(Proceedings Inst. M. E. 1870.)

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WARSOP AERO-STEAM ENGINE. *Plate 71.*

Fig. 12. *Indicator Diagrams*

showing Air-pump Resistance and Engine Friction.

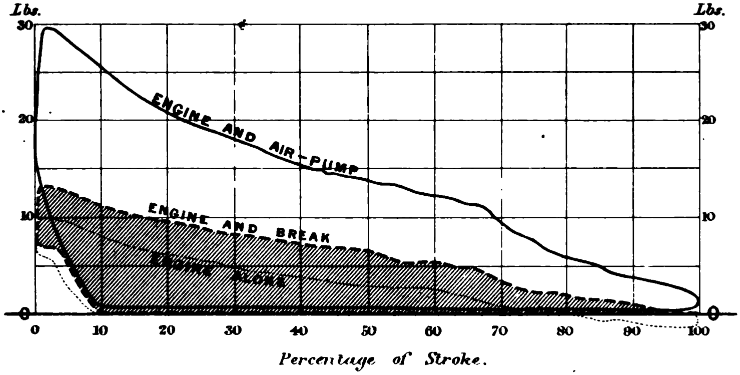
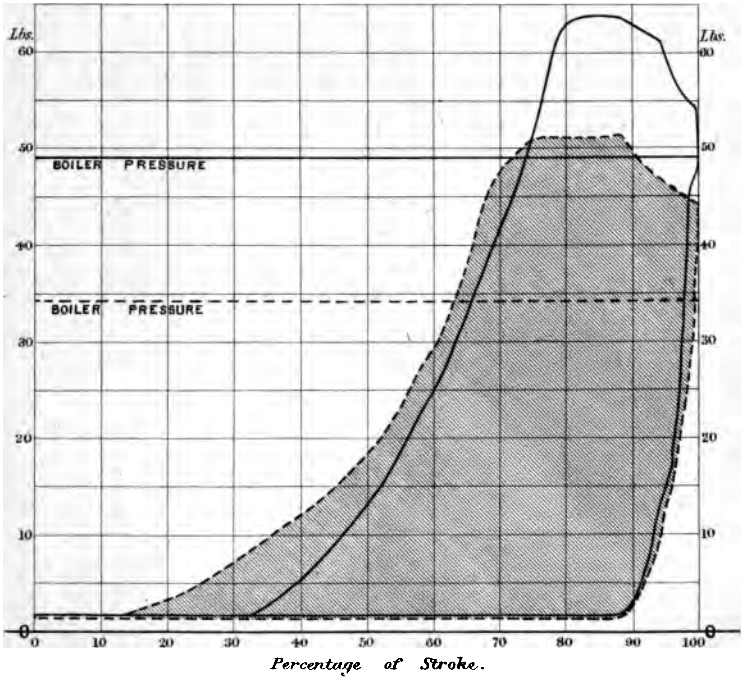


Fig. 13. *Indicator Diagrams*

showing Air-pump Compression.



(Proceedings Inst. M. E. 1870.)

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WARSOP AERO-STEAM ENGINE. *Plate 71.*

Fig. 12. *Indicator Diagrams*

showing Air-pump Resistance and Engine Friction.

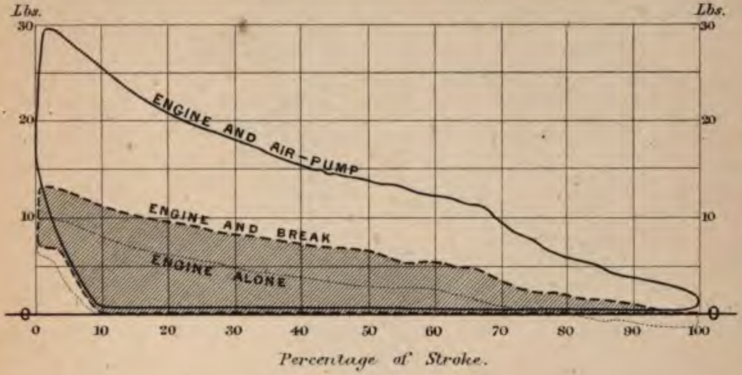
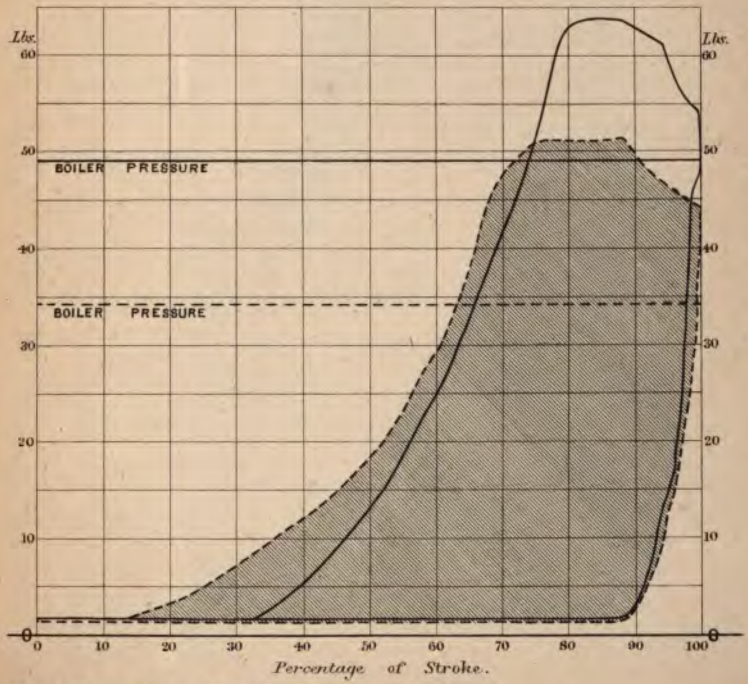


Fig. 13. *Indicator Diagrams*

showing Air-pump Compression.



(Proceedings Inst. M. E. 1870.)

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WIRE-ROPE BRIDGE.

Plate 72.

Fig. 1. *General Elevation.*

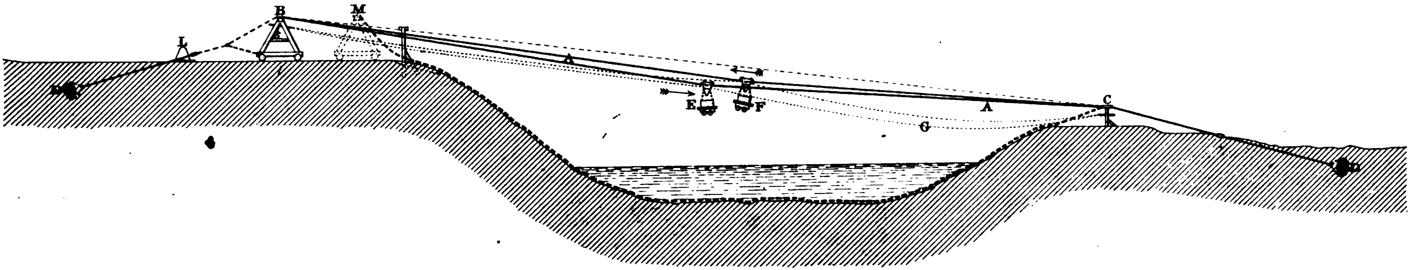
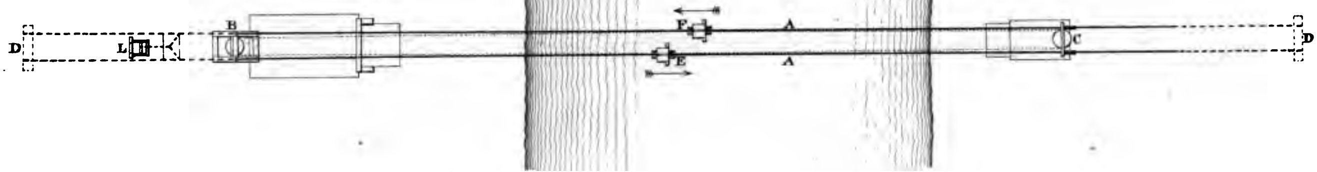


Fig. 2. *Plan.*



(Proceedings Inst. M. E. 1870.) *Scale* 1/600th

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WIRE-ROPE BRIDGE.

Fig. 3. *Elevation of Framing &c. at upper end of bridge.*

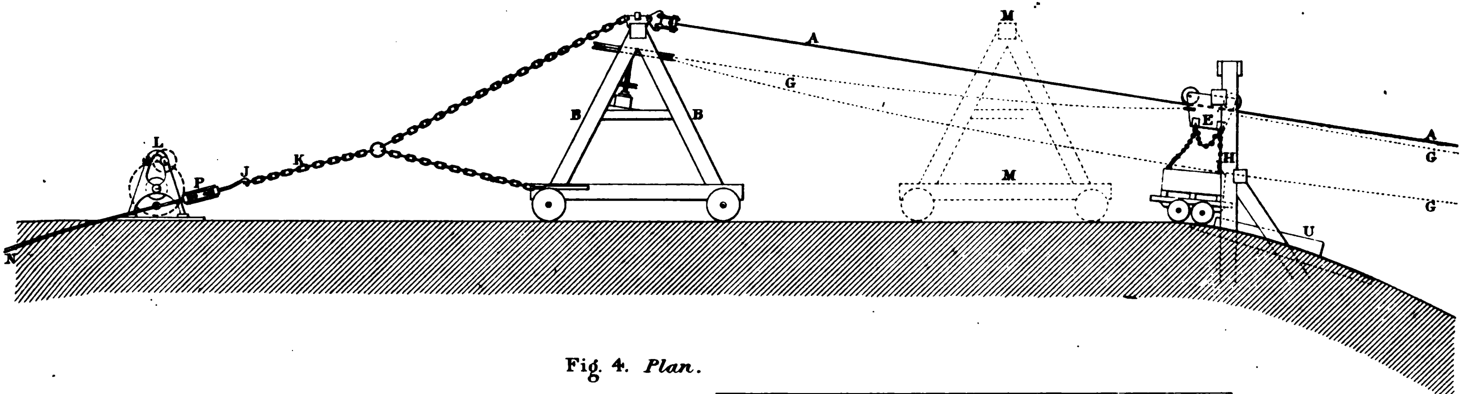
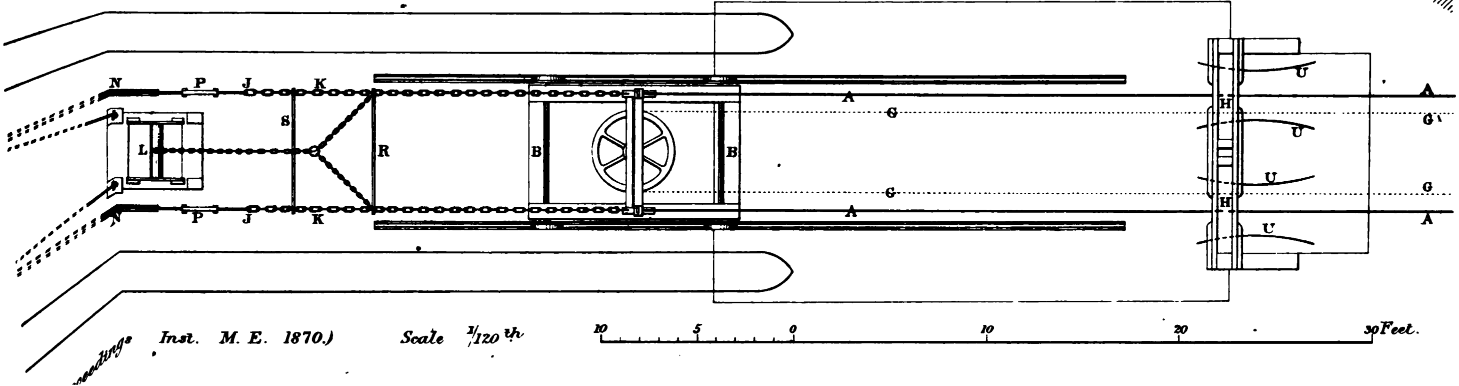


Fig. 4. *Plan.*



ceedings Inst. M. E. 1870.) *Scale 1/120th*

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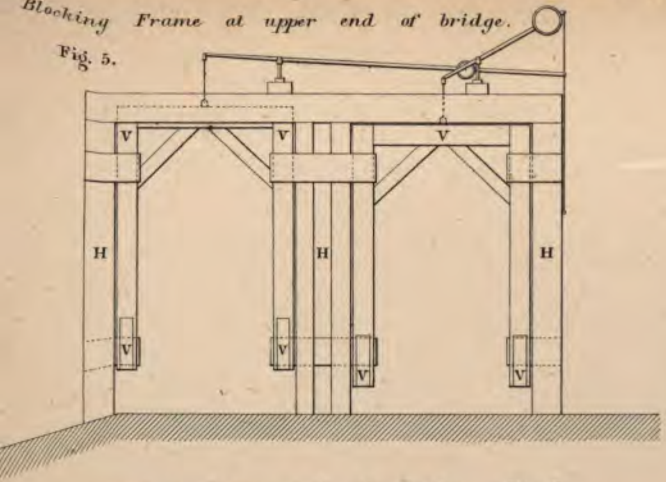
WIRE - ROPE BRIDGE.

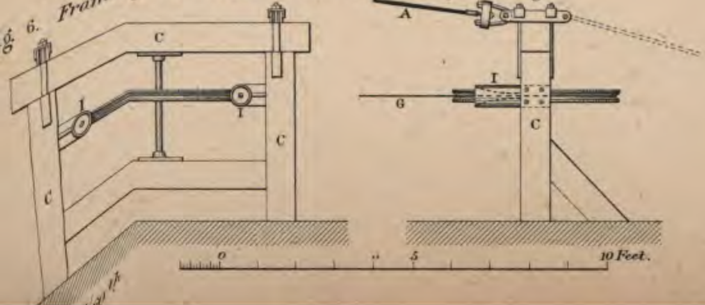
Plate 74.

Blocking Frame at upper end of bridge.

Fig. 5.



g. 6. *Framing at lower end of bridge.* Fig. 7.



Fixing of ends of Wire Ropes.

Fig. 8.

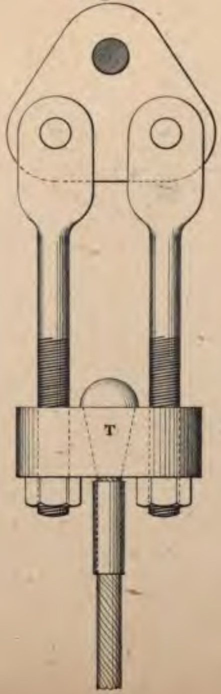


Fig. 9.

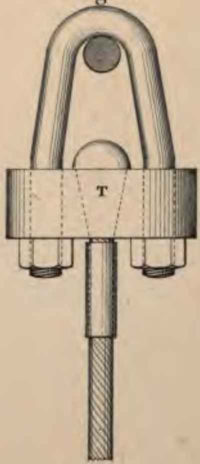
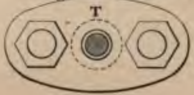
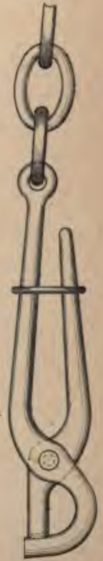


Fig. 10. *Plan.*



Suspending Hook for Trucks.

Fig. 11.



Scale 1/8 th.

(Proceedings Inst. M. E. 1870.)